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STRUCTURAL LINEAMENT AND PATTERN ANALYSIS OF MISSOURI,  
USING LANDSAT IMAGERY

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|  |  |                                      |                            | 14. Sponsoring Agency Code   |  |
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## PREFACE

### Objectives:

To assess the quality, characteristics and overall value of the LANDSAT satellite imagery in resources investigations in a structurally distinct unit of the Midcontinent Platform that is composed of varied rock types, is characterized by differential erosion and is subjected to intensive fracturing and faulting through:

1. Qualitative and quantitative methods of lineament detection and description of lineament parameters, geophysical and geological.
2. Evaluating and interpreting metallotects in mineralized areas i.e. geometric relationships between mineral deposits and lineaments.
3. Utilizing lineament studies for basic geological research.

### Scope of work:

1. Analysis of available images covering the state of Missouri 180,000 square kilometers (70,000 square miles).
2. Quantitative analysis of selected areas in the area of the Ozark Dome.
3. Ground truth mapping of selected areas.
4. Collection of supporting subsurface geological and geophysical data.

### Conclusions:

1. Satellite image analysis has contributed much to the geological knowledge of the area and will be a useful tool in mineral resource and structural studies.

### Summary of recommendations:

It is recommended that the study be continued focusing on:

1. Regional structural studies
2. Metallotects of major mineralized areas
3. Regional hydrogeologic studies
4. Additional ground truth investigations
5. Regional studies beyond the boundaries of the State.

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## I. INTRODUCTION

The most important objective of this study is to determine the extent and usefulness of satellite imagery in furthering knowledge of the geology of Missouri and its mineral resources and in improving techniques for basic geological research.

Missouri provides a geologically varied test area for evaluating LANDSAT imagery in the Platform or Central Stable Region of the Midcontinent. Parts of the state lie within the Central Lowlands (southern limit of the Glaciated Plains and eastern margin of the Western Plains), the Ozark Plateau, and the Mississippi Embayment of the Coastal Plains Province (Southeast Embayment). General boundaries of the geomorphologic subdivisions within the state shown on Figure 1 are: the Glaciated Plains extending across the northern half of the state; the Western Plains in the southwest quarter; the Ozarks in the south-central and southeastern parts; and the Southeast Lowlands in the extreme southeast corner.

Topography varies from the highly dissected, rugged Ozark hill country to the flat alluvial plain of the Southeastern Lowland. The west, southwest and northeast are relatively smooth, low-relief plains. The northwestern and north-central parts consist of low, rolling to hilly country. Within the Ozarks are the St. Francois Mountains, an exhumed Precambrian surface; the highest point in the state, 540 m (1772 feet) above mean sea level; and the area of greatest maximum relief, about 300 m.

Precambrian igneous rocks, chiefly silicic ash-flow tuffs and granites, are exposed in the St. Francois Mountains in Southeast Missouri. Surrounding and dipping away from the igneous outcrops are Paleozoic marine strata of limestones, dolomites, sandstones and shale units. In northern Missouri, coal deposits are present in Carboniferous strata. Cretaceous and Tertiary clays, silts and sandstones crop out in the southeastern corner of the state. Pleistocene deposits, mostly glacial till and loess, blanket the northern third of the state (fig. 2).

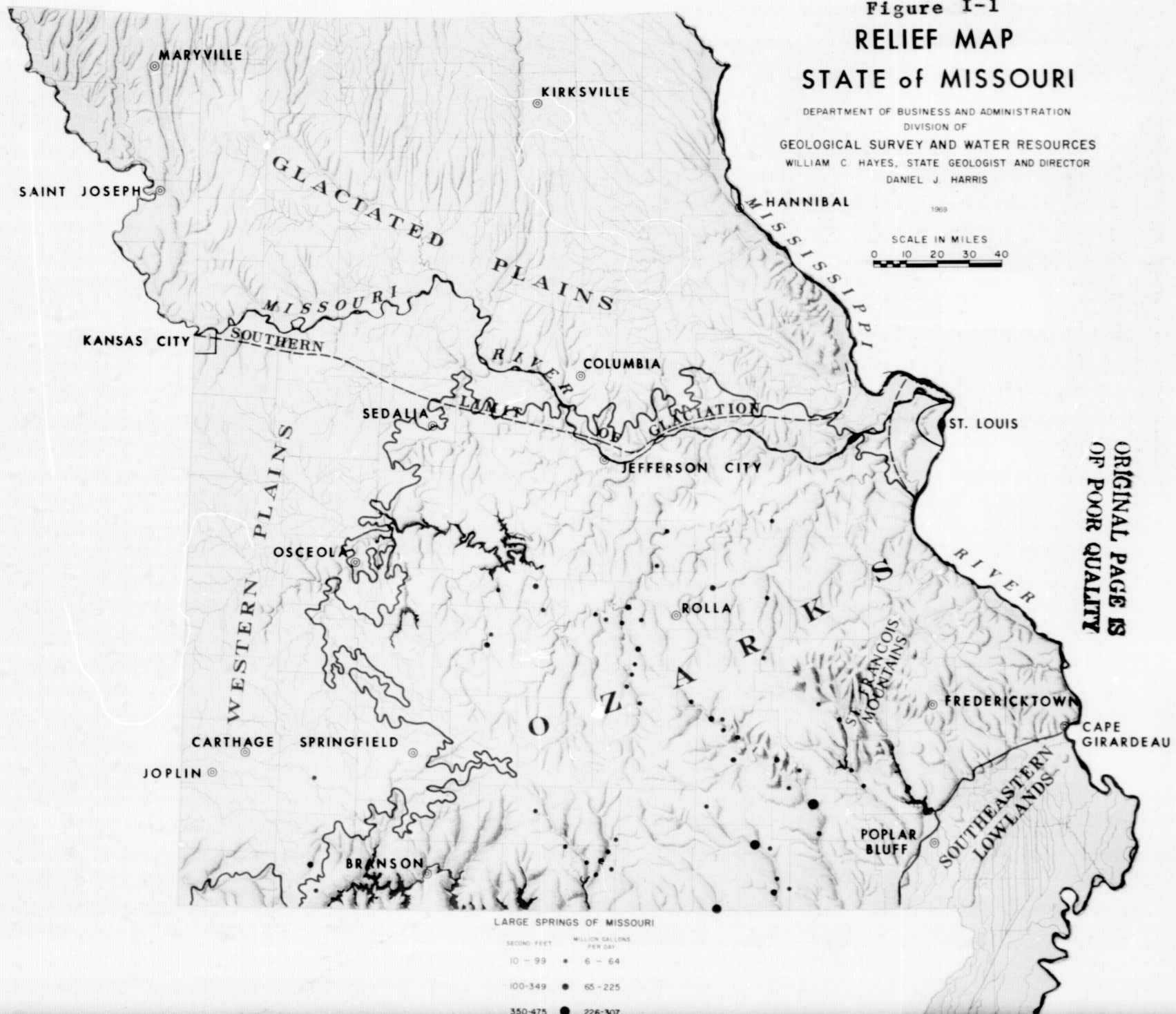
As part of the tectonically stable Midcontinent region, the bedrock is relatively flat-lying; however, important structural features of the Central Stable Region are present in the State of Missouri. The dominant structure is the Ozark dome, a structurally complex, block-faulted uplift. Major areas of faults are in southeastern and southwestern Missouri, the principal areas of metallic mineralization in the state. Some of the major faults and fracture zones appear as major structural lineaments and are part of regional or subcontinental-size structural features. The sedimentary rocks display a variety of structures, including gentle folds, anticlines, synclines, and normal and strike-slip faults. The principal trend of fold axes is northwest-southeast, which is also the main trend of joints, fractures and lineaments. Major faults in the southeastern and southwestern parts of the state also have dominantly northwesterly strikes (McCracken, 1971).

Figure I-1  
RELIEF MAP  
STATE of MISSOURI

DEPARTMENT OF BUSINESS AND ADMINISTRATION  
DIVISION OF  
GEOLOGICAL SURVEY AND WATER RESOURCES  
WILLIAM C. HAYES, STATE GEOLOGIST AND DIRECTOR  
DANIEL J. HARRIS

1969

SCALE IN MILES  
0 10 20 30 40





ORIGINAL PAGE IS  
OF POOR QUALITY

I-3

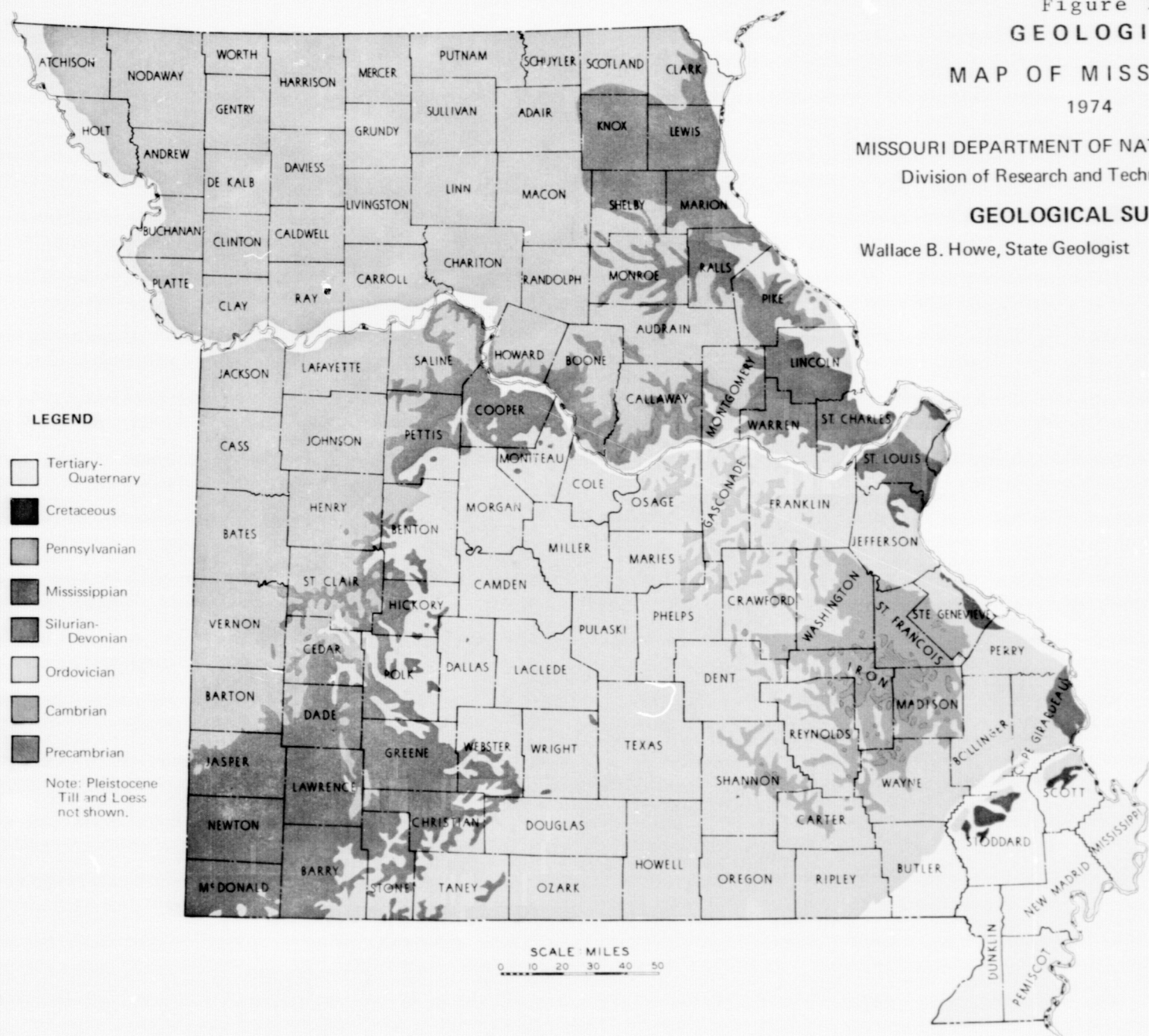


Figure 3  
**GEOLOGIC TIME SCALE, TYPES, AND USES OF MISSOURI ROCKS**

| MAJOR DIVISIONS   |   | TYPE AND DISTRIBUTION OF ROCK   | ECONOMIC UTILIZATION  |
|---|---|---|---|
| ERAS  | PERIODS   |   |   |
| CENOZOIC  | QUATERNARY <sup>0</sup><br>1,000,000<br>Q   | Glacial deposits; loess; silt, sand, and gravel in modern streams and rivers.   | Parent material of much of state's soil; important source of water; chief source of sand and gravel.  |
|   | TERTIARY <sup>1</sup><br>63,000,000<br>T  | Sand, gravel, clay, and shale; largely restricted to Lowland region of south-eastern Missouri.  | Water, ceramic clay, bleaching clay.  |
| MESOZOIC  | CRETACEOUS <sup>64</sup><br>72,000,000<br>K   | Clay and sand; restricted to south-eastern Missouri as above.   | Water, ceramic clay, sand.  |
|   | JURASSIC <sup>136</sup><br>46,000,000<br>J  | No rocks of Jurassic age in state.  |   |
|   | TRIASSIC <sup>182</sup><br>49,000,000<br>R  | No rocks of Triassic age in state.  |   |
| PALEOZOIC   | PERMIAN <sup>231</sup><br>50,000,000<br>P   | Sandstone; known from single locality in Atchison County.   | No economic utilization.  |
|   | PENNSYLVANIAN <sup>281</sup><br>30,000,000<br>IP  | Shale, limestone, sandstone, clay, and coal; present in more than two-thirds of the counties of the state; extensive in western and northern Missouri.  | Coal, ceramic materials (including fireclay); limestone and shale for cement manufacture; oil, gas, and water; an important source of limestone in many western and northern counties; asphaltic sandstone, and iron. |
|   | MISSISSIPPIAN <sup>311</sup><br>35,000,000<br>M   | Predominantly limestone, some shale; principal areas of outcrop are south-western, central, east-central, and northeastern parts of the state.  | Lime, limestone, marble (Carthage), raw material for cement, water, tripoli, lead, zinc, and iron.  |
|   | DEVONIAN <sup>346</sup><br>60,000,000<br>D  | Predominantly limestone; exposed in central, eastern, and southeastern Missouri.  | Limestone, marble (Ste. Genevieve Co.).   |
|   | SILURIAN <sup>406</sup><br>20,000,000<br>S  | Predominantly limestone; exposed in northeastern and southeastern Missouri.   | Limestone and dolomite.   |
|   | ORDOVICIAN <sup>426</sup><br>75,000,000<br>O  | Dolomite (magnesian limestone), limestone, sandstone, and shale; extensively exposed in Ozark area as far north as Montgomery County and west to McDonald and St. Clair counties; also exposed in parts of Ralls, Pike, and Lincoln counties. | Sand for glass and ground silica, limestone, dolomite, water, oil (St. Louis County), building stone, raw material for cement, iron, and terrazzo chips.  |
|   | CAMBRIAN <sup>501</sup><br>100,000,000<br>C   | Dolomite, sandstone, and shale; major outcrops restricted to St. Francois Mountain area.  | Lead, zinc, silver, cobalt, nickel, copper, barite, iron, water, dolomite, terrazzo chips, and building stone.  |
|   | PRECAMBRIAN <sup>601</sup><br><i>Includes several divisions of Era rank. Total time involved may have been as much as four billion years.</i> | Igneous and metamorphic rocks; igneous exposed in St. Francois Mountain area.   | Iron, granite for building and monumental stone.  |
| <p>NOTE: Age data based on latest published results of isotopic measurements.<br/>Chart not drawn to scale; 0-601: cumulative age in millions of years.</p> |   |   |   |

MARCH 1964

Across Missouri, along the 38° North latitude, there are a number of circular to subcircular features, some of which have been identified as meteor impact structures, while others appear to be the result of volcanic activity. The term "cryptoexplosive" has been applied to some structures designating the possibility of either meteorite impact or deep-seated volcanic origin.

The Precambrian core of the Ozark dome is the exposed part of a 2400 km long, by 300 to 500 meter wide, 1.5-b.y. old, ore-bearing geotectonic unit, the Central Province. This igneous province is present mostly in the southern half of the state, underlying the Paleozoic sediments. In the northern part of the state, the sedimentary rocks are underlain by igneous and metamorphic rocks, similar to and possibly correlative with the Churchill Province of the Canadian Shield. The structural grain of the basement is reflected in the deformation style of the sediments and may be investigated by photogeologic methods and image analysis.

Missouri has several major metallogenic provinces with economically important lead, zinc, copper, silver and iron production. Industrial minerals, including barite, are produced in large quantities. Petroleum and natural gas are produced in small amounts. A large area of tar sand is present in the western part of the state. Significant and well-distributed groundwater resources are available in aquifers located principally in the Ozark region.

A systematic study of satellite images for potential geological discoveries may be utilized in Missouri as well as in other parts of the Midcontinent where the sedimentary blanket and the glacial drift are much thicker. Missouri appears to be one of the key states in several respects for improving our geologic knowledge of a large part of the Midcontinent.

## II. PURPOSE AND SCOPE OF INVESTIGATION

The principal objectives of this project are:

1. To assess the quality, characteristics and overall value of the ERTS-LANDSAT satellite imagery in resources investigations in a structurally distinct unit of the Midcontinent Platform that is composed of varied rock types, is characterized by differential erosion, and is subjected to intensive fracturing and faulting.
2. To evaluate and interpret the imagery for detecting natural resources with emphasis on the metallotects of the large mineralized districts in the area.
3. To evaluate the imagery for recognizing and identifying gross rock types as an aid in regional-scale geologic mapping.

During the course of the investigation, its principal objectives had to be modified due to the large number of major lineaments and circular features observed on the imagery. Much more time than was planned originally had to be spent on tracing, studying, field checking and describing the lineaments. Because of time limitations objectives nos. 2 and 3, metallotect research and rock-type recognition, have been given less emphasis. Image analysis provided so much new information regarding the geology of the state that it will take several years and subsequent studies to evaluate all data.

While the project covered the entire state, it concentrated on the Ozark dome, an elongated structural uplift comprising an area of 48,000 square km. The Ozark dome includes three major subdivisions: the St. Francois Mountains Precambrian igneous core; the volcanic knobs of the Eminence area; and the surrounding outcrops of Paleozoic formations. The exposed Precambrian igneous core is composed of a volcanic supergroup dominated by high-silica volcanic flows and ignimbrites and an intrusive suite of several composite batholiths and stocks. In many parts of this terrain, soil cover is thin to absent while deciduous forest and some pines are present. The topography is relatively rugged and the highest "peak", Taum Sauk Mountain, reaches 540 meters above sea level. The sedimentary cover that dips quaquaversally from this Precambrian core is nearly horizontal, but locally, near the igneous knobs, dips are steep. Groundwater movement has formed karst features in the carbonate rocks.

Part of the Ozark dome, centered around the Belleview basin, was selected for quantitative studies. Quantitative analytical methods such as analog image analysis using IDECS image enhancement, multi-channel optical scanning, and digital image analysis by computer revealed geologic features not recognized or visible to the human eye on the LANDSAT transparencies. Effort was made to differentiate and enhance features which were faint or invisible

to the naked eye by density slicing and color combination enhancement. An attempt was made to differentiate linears from surrounding areas by computer analysis. Tape recording computer printout was made for a selected area. Black and white and color video displays were photographed and studied.

In the last phase of the work, effort was made to collect supporting geological and geophysical data including "ground truth" field checking and surveying of recognized features in selected areas.

### III. DATA-GATHERING SYSTEM, METHODOLOGIES FOR MAPPING AND RECORDING

#### 1. Photogeologic Analysis of LANDSAT Images

Conventional photogeologic analysis of MSS bands 5 and 7 transparencies and prints were completed for the entire state. False-color composites (Diazochrome) of Southeast Missouri also were studied. Equipment used in this phase of study included light tables, projection equipment, magnifying glass and magnification to the scale of available geologic maps. Visual study of images involved checking of linear features, low and high contrast features and textural patterns.

Visual analysis of images resulted in the location of more than 90 percent of all linears found. Enhancement methods did, however, result in new discoveries. Bedrock lithologies were distinguishable only where expressed by erosional patterns. Igneous rock outcrops of the St. Francois Mountains were recognized on this basis.

Locating features on base maps introduced a certain amount of cartographic errors. Theoretical error within a given MSS image measuring a single scale factor may result in less than 200-meter displacement of an object. In this investigation, it was found that the transfer of an image feature to a base map of 1:1,000,000 and 1:500,000 resulted in a much larger error, measurable in kilometers. Visual correction was necessary in order to minimize errors by relating image features to topographic, drainage or political features on the base map. Checks were also made at the intersection of lineament features and at the end point of straight lines. It was also found that tracing of lineaments from the work map to other bases introduced slight errors when the draftsman placed his pen slightly off the lines to be copied. These cumulative errors are somewhat compensatory. It was felt by the investigators that a relatively thick (3 to 4 mm) line should represent the major regional lineaments on the 1:1,000,000-scale maps since many of these lineaments are complex "zones" of geological linears and not narrow lines such as the trace of a single fault.

Multiscale analysis of linears showed that single linears at 1:1,000,000 scale became segmented at 1:200,000 or larger scales and may be composed of shorter parallel, an echelon, or conjugate linears. Study of an aerial photomosaic of the Annapolis lineament showed this kind of segmentation.

The ability to see small features on the images was limited. The theoretical instantaneous field of view (IFOV) which is a measured resolution for good contrast linear target is given for LANDSAT images as 79-meters square. Investigators

report observation of farm ponds with an approximate diameter of 200 meters. Consequently, one will not discover a narrow fault line on the images unless it is "enhanced by nature" (fault escarpment, vegetation, differential erosion). Thus many faults mapped in the field may not be seen on the images even if they are in the lineament zone. Fault zones which coincide with larger features and have dimensions of hundreds of meters across to their linear trends are easier to observe. This factor may be overlooked by geologists accustomed to analyzing air photos on which narrow fault lines can be observed.

It was found that features visible on one image may not be visible on another. Therefore, several images, especially different seasonal coverage, should be studied in the repetitive system. Radiometric accuracy depends on a series of factors and the radiance of a feature may be influenced by the sun angle as well as by the nature of foliage, soil, snow cover, etc. It is extremely difficult to pinpoint objectivity versus subjectivity in feature recognition. Undoubtedly, there is a subjective element in feature recognition, biased by the investigators' geologic knowledge of the area and by the difference in perception of patterns, textures and contrasts by individuals.

2. Analog Image Analysis by IDECS (Image Discrimination, Enhancement and Combination System)

The IDECS of the University of Kansas Space Technology Center, Lawrence, Kansas is an analog-digital real-time processing system. By converting image data into analog electrical signals, a wide range of enhancement and combination techniques is possible "in real time". The lack of intensity resolution on the black and white picture was eliminated by using a color television monitor as an output device and color coding the image on the screen. Boundary enhancement, level selection, combination and assignment of color can be achieved by skillful operation of the analog and digital circuits of the IDECS.

LANDSAT image transparencies were used as input format and the video scanner was used to convert image data into corresponding electrical signals for processing. To study the circular and linear features on the output screen, a light background color (pastel yellow, pink, green) was selected on which dense colors (deep red, purple, green or black) were superimposed by the operator to enhance and discriminate image features on the screen. Transforming the monochrome image to a polychrome display brought out a wide variety of enhanced features, some which were not seen on the black and white transparencies. A wide selection of color coding and combinations were tested for the same feature, resulting in a variety of pictures that differed somewhat in output value from the point of view of enhancement and recognition. A study area was



selected on the Southeast Missouri frames and enhanced features were photographed on color film.

Edge enhancement was used to differentiate and amplify analog signals in order to discriminate boundary information or increase contrast in an input image. The extraction of density slices from input images and their transformation into enhanced derivatives displayed on a black and white or colored television screen, resulted in recognition of some features not identified in the visual study of the images. Edge enhancement is relatively simple, but its effectiveness is partly dependent on the orientation of linear features and partly on the skill of the user in recognizing and interpreting features. Consequently, such an investigation should first be made in a known area.

### 3. Digital Analysis Using KANDIDATS

Processing of LANDSAT tape (ID 8121516125) of a scene covering part of Southeast Missouri was also done at the University of Kansas Space Technology Center.

The first step was to extract and convert Strip 2 of the LANDSAT tape from the 9 track 800 bpi to 7 track 556 bpi tape format. This allowed it to be read into their PDP-15 system under the KANDIDATS (Kansas Digital Image Data System) software. The "TERTS" command performed this function. Rows 800 through 1299 and columns 1 through 800 were read in and stored on disk file in a format compatible to KANDIDATS.

This 500-rows-by-800-columns picture consisted of the four MSS bands 4, 5, 6, and 7. The dynamic range of the data ranged from 0 to 127, requiring seven bits of information to be stored for each band pixel.

This first processing step was to equal probability and quantize the image from 128 to 32 gray levels. In this process, each band was treated separately. The operation amounts to reassigning the gray tones so that each of the 32 levels has about the same number of pixels. This brought out a number of features which were indistinct or not seen on the original images. MSS bands 5 and 7 of this image were printed out at reduced size by sampling every second row and column. The printout was also adjusted for LANDSAT skew and scaled to about 1:45,200.

The four quantized bands were further enhanced by the KANDIDATS operation "EHNUM". The process calls for replacing each pixel by the minimum or maximum of its four vertical and horizontal neighbors, depending on which of its gray tone is closest. This increases the contrast in the image, making the edges a little sharper.



Gradient operations were also done. A gradient operation computes the spatial derivative for each pixel based on all the bands. A cell in the gradient picture is assigned a high/low value if its spatial derivative was high/low. A high value corresponds to an edge, while a low value suggests a homogeneous neighborhood. When displayed on the TV screen, the edges stand out as whiter areas, while the homogeneous regions remain dark. The two gradient operations carried out were the Roberts Distance 1 and the Laplacian. The latter did not generate a good result and was discarded. The Roberts gradient was printed out and used for more processing.

To extract the edge areas from the gradient picture, some single level slicing was performed. The KANDIDATS command "TRSLD" was used for this. The thresholding is done as follows: First, the running mean for each row is determined (this is based on 10 rows above and below the row under consideration); each row is then thresholded by a fraction of its running mean. Five level slicing operations were done using fractions 1.3, 1.4, 1.5, 1.6, and 2.0 for the running means. The images corresponding to the first four parameters were also cleaned for noise by using the operator "CLEAN". By examining the eight neighborhood of each cell, it was determined if the cell was an isolated noise point or not. If it was considered so, it was deleted.

The thresholded and cleaned images were also printed out at the same scale as the quantized bands and the gradient image. Intensity resolution of the printouts was limited to 13 levels and they were found to be fair for determining gross features.

Analysis of the printout of the quantized and enhanced images gave an interesting result. The printout of the quantized image showed linear segments better than the original black-and-white transparency, but the overall quality of printout was such that it was difficult to evaluate if one did not know of the linears beforehand.

The printout of the gradient image was relatively poor and hardly usable.

Selected areas were examined on the IDECS which can be used to display digital pictures. In the digital mode, up to three images may be superimposed on the screen. This operation permitted comparisons of different combinations of original quantized, enhanced and gradient images. The "original", the "extracted gradient" and a "combination" were used by the investigators in color and in black and white. The color display generally seemed to be better suited for geological analysis. Our judgment was that the combination of color original and gradient was the most useful tool in comparing details with the black and white transparencies. Detailed

analysis was made of selected areas displayed on the IDECS system which exhibited excellent details of regional fracture systems as well as other features of the volcanic terranes in Southeast Missouri. Due to the shortage of time a satisfactory systematic analysis of each display could not be completed.

#### 4. Photography of IDECS/KANDIDATS TV-Image Display

Color and black-and-white photography were used to record the enhancements performed on the IDECS. Both photographs and slides were examined and the linear traces on the image transparencies were compared with the color enhanced imagery.

Photographs were made of the IDECS displays shown in three modes: on a black-and-white TV unit; on a color TV unit; and on a third unit consisting of three monochromatic (red, blue and green) TV units aligned to merge the image by mirrors onto a single screen.

The photography was recorded with 35-mm cameras (Nikon and Minolta) with 50-mm (normal) lenses on a heavy tripod. Slow shutter speeds (1/30 to 1/4 sec.) were used requiring cable releases. Light settings, set according to a handheld Minolta Spotmeter light meter, ranged from f/5.6 to f/2. High Speed Ektachrome (ASA 160) and Plus-X (ASA 80) panchromatic films were used at the recommended ASA settings. The camera to screen distance was 1.2 meters for the single TV receivers and approximately 2 meters for the merged image.

The black-and-white display unit was troublesome and the "noise" in the unit caused all images to photograph poorly.

The color TV screen displayed images well and the slides made were also good. The color coding of gray tones enabled a quick analysis of contrasting tones and linear color changes. Color could be adjusted at will.

The three monochromatic TV units produced a merged image that was small but sharp and while adequate for visual examination the set-up of these units did not allow for full-frame or good quality slides. Unfortunately, display of the computer compatible tape by KANDIDATS/IDECS was restricted to this unit.

#### 5. Image Processing by Computer Program at University of Missouri-Rolla

The facilities of the UMR Computer Center were also used for examination of the computer-compatible tape of the Southeast-Missouri scene. The CCT was demultiplexed to the four multispectral images and a random-access file was produced in a convenient form for processing programs to be developed at a later stage. The demultiplexed data were displayed as a

half-tone image on a Tektronix (T-4014) graphics terminal which has a capability for displaying 4,096 to 3,120 points with up to 64 different levels of intensity. Thus, two programs were utilized: One, a program to read 9-track LANDSAT CCT format tapes producing a demultiplexed image file on a random-access storage disk consisting of I.D., annotation and image data and, secondly, a program to display image files produced by the first program on a Tektronics T-4014 graphics terminal using the special point-plot mode. Study and evaluation of the visual point plot can then be compared to other methods of investigation.

A plot (histogram) of the relative frequency of gray levels (255) for specific MSS bands (4, 5, 6 or 7) was made which permits further examination of subtle changes in the spectral characteristics of vegetation, soil, rocks and water which may enhance linear traces. This can be an important approach in analysis where linears are either obscure or perhaps even "invented" by statistical programs. Future use of the histogram data can be made in experimenting with pattern recognition schemes where the importance of regional geologic, geomorphic and surficial materials features may be studied. Although no immediate plans have been formalized in this regard, there is interest in this application in mined-land analysis.

#### 6. Supporting Maps Used in Linear Analysis

Basically, the study was an office evaluation rather than a field investigation of the relationship of the linear and circular elements observed on the satellite imagery to the structural framework of the state. Statewide plots were made at 1:1,000,000 scale as direct overlays from the positive transparencies (7.3 inch standard product) and at the enlarged scales of 1:500,000. The following maps, at the 1:500,000 scale, were the principal ones used:

- a. Geologic Map of Missouri, 1961, compiled by Mary H. McCracken;
- b. Structural Features Map of Missouri, 1971, compiled by Mary H. McCracken;
- c. Magnetic Map of Missouri, 1943, Missouri Geological Survey & Water Resources;
- d. Gravity Map of Missouri, 1943, Missouri Geological Survey & Water Resources;
- e. Mineral Resources & Industry Map of Missouri, 1965, compiled by Eva B. Kisvarsanyi and Walter V. Searight;
- f. Configuration of the Precambrian Surface and Major Structural Lineaments of Missouri, 1962, William C. Hayes;

- g. Paleotopography of the Precambrian Surface in Missouri, 1975, Eva B. Kisvarsanyi;
- h. Base Map of Missouri, 1971, U. S. Geological Survey;
- i. Shaded Relief and Drainage Map of Missouri, 1952, U. S. Geological Survey; and
- j. "Army Map Service Series", 1° x 2°, 1:250,000 scale, U. S. Geological Survey.

The 1:1,000,000 scale standard bulk product image is adequate for matching base map planimetry up to scales of 1:250,000.

In addition to the above cited maps, unpublished geologic maps at scales of 1:24,000 and 1:62,500, aerial photography and topographic maps were used.

#### 7. Field Investigation of Lineaments

Once lineament traces were identified on the LANDSAT imagery and plotted on base maps, the next step was the field investigation. Seven areas, four with ongoing mapping projects, were selected to be checked for field evidence of the lineaments observed on the imagery (fig. III-1). An eighth area having a distinct double circle or "bullseye" was recommended to the Department of Geology and Geophysics, University of Missouri-Rolla, as a test site for a field project in geophysical methods. Both gravity and magnetic ground surveys were conducted over the area. In five of the seven areas being mapped, the LANDSAT lineament map was used as a guide to areas to be checked for field evidence of folds, faults, joints, fracturing or mineralization, the presence of which would indicate that the linear truly reflected a geologic structure. In the other two areas the structure was identified and mapped without reference to the imagery and comparisons were made following the field investigation.

Examination of topographic maps and stereo-photo pairs covering the areas to be field checked preceded actual field investigation. Topographic maps often revealed or supported the presence of lineament traces. Photo-pairs provided a detailed view of small-scale topographic features including joint and fracture patterns, possible fault traces, drainage patterns and areas of exposed bedrock. The LANDSAT traces, features revealed by photo-pairs and other available geologic data, were plotted on the topographic maps of the area to be checked.

Field checking consisted of actual on-the-spot investigations of features thought to be related to major lineaments. The density, strike and dip of joint and fracture patterns

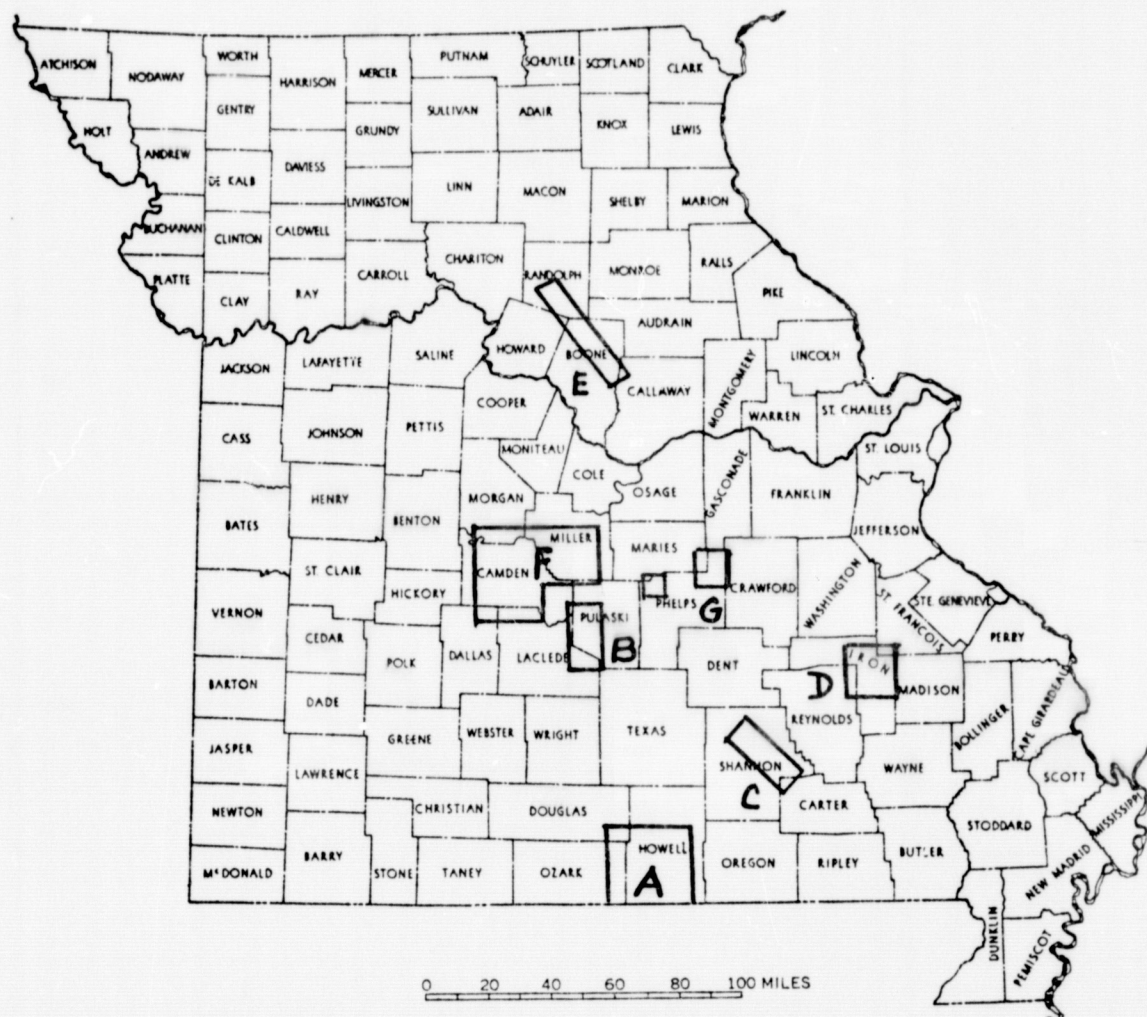


Figure III-1  
AREAS OF FIELD INVESTIGATION

were recorded. Displacement of rocks, fault gouge and brecciation were taken as indications of a fault in the area. Any fault traces found were noted and mapped on a reconnaissance basis. Zones of alteration and mineralization were also noted. In igneous terranes, mafic dikes and quartz veins were noted along with their strike and dip. Location of springs and stream-flow characteristics which appear to be related to lineament traces were recorded.

In some cases when time permitted, reconnaissance geologic mapping was done along the lineament traces; however, due to the very large area covered and the numerous lineament traces checked, along with the inaccessibility of some of the areas, part of the field checking can only be regarded as rough reconnaissance. Much previously unrecorded geologic structure was revealed and the nature of many of the lineaments as major features was verified.

#### IV. DESCRIPTION OF LINEAR & CIRCULAR FEATURES

Examination of LANDSAT imagery resulted in the recognition of a large number of major linear and circular features which, in itself, represents a great forward step in understanding the outstanding geological-structural features of the state. Although the most spectacular area of linear display is in Southeast Missouri in the area of the St. Francois Mountains and south of the 38° north latitude, some important lineaments were seen and traced into the drift-covered northern part of the state.

Tracing and plotting the lineaments on a 1:1,000,000-scale map indicated a distinct pattern of linear features throughout the state that, in general, follow major structural trends. The dominant systems follow the NE, NW, NS and EW directions and mostly reflect structural features of the Precambrian basement of the Platform and those of the overlying sedimentary cover. Coincidence of lineaments traced from imagery and known structural features in the state is high, thus supporting a causative relation between them. The lineament pattern apparently reveals the fundamental style of deformation in the craton, as well as the close relationship between the image features and ground-truth data. This is one of the most important contributions of imagery study because it enabled investigators to delineate dozens of heretofore unknown linear features that are related to epeirogenic movements and deformation of this segment of the continental crust. It is anticipated that the LANDSAT lineament map of Missouri will prove to be valuable in a variety of geological studies, including planning exploration for natural resources.

##### 1. Northeast-Trending Lineaments

The northeast-trending lineaments are generally restricted to the southern half of the state. Some of them extend into northern Arkansas, Illinois and Kansas; many can be traced across the state and have lengths of more than 400 km. The lineaments are generally parallel or subparallel to each other. Some of them intersect at sharp (20°-30°) angles. Noted intersections are present in the southwestern and northwestern parts of the state.

Thirty-three northeast-striking linears are numbered (e.g., #3 NE) in succession from the southeast to the northwest. Names are informal and are used only if they assist in identification, if mapped or if other data support the assumption that the linear is a structural or major physiographic feature. Figures IV-1 thru IV-5 show their general relationship to the relief, geologic setting, major structural features, magnetic anomalies and principal mineral commodity areas in the state.

#1 NE ("Bootheel lineament") Strike N61°E; length 100 km

The lineament is in the Mississippi Embayment or Bootheel area of Missouri and can be traced from the Missouri-



Figure IV-1  
RELIEF MAP  
STATE of MISSOURI

DEPARTMENT OF BUSINESS AND ADMINISTRATION  
DIVISION OF  
GEOLOGICAL SURVEY AND WATER RESOURCES  
WILLIAM C. HAYES, STATE GEOLOGIST AND DIRECTOR  
DANIEL J. HARRIS

1969

SCALE IN MILES  
0 10 20 30 40

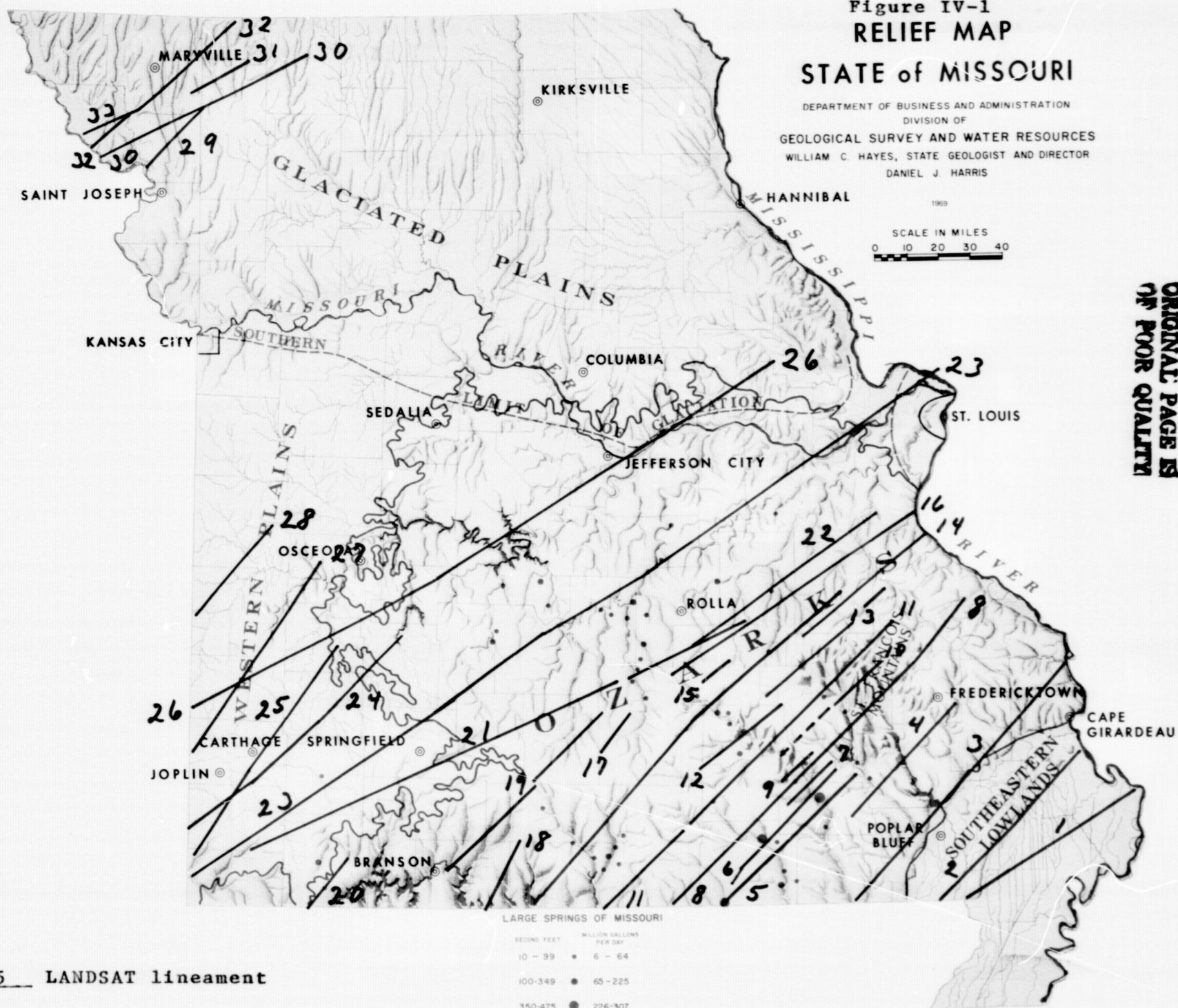




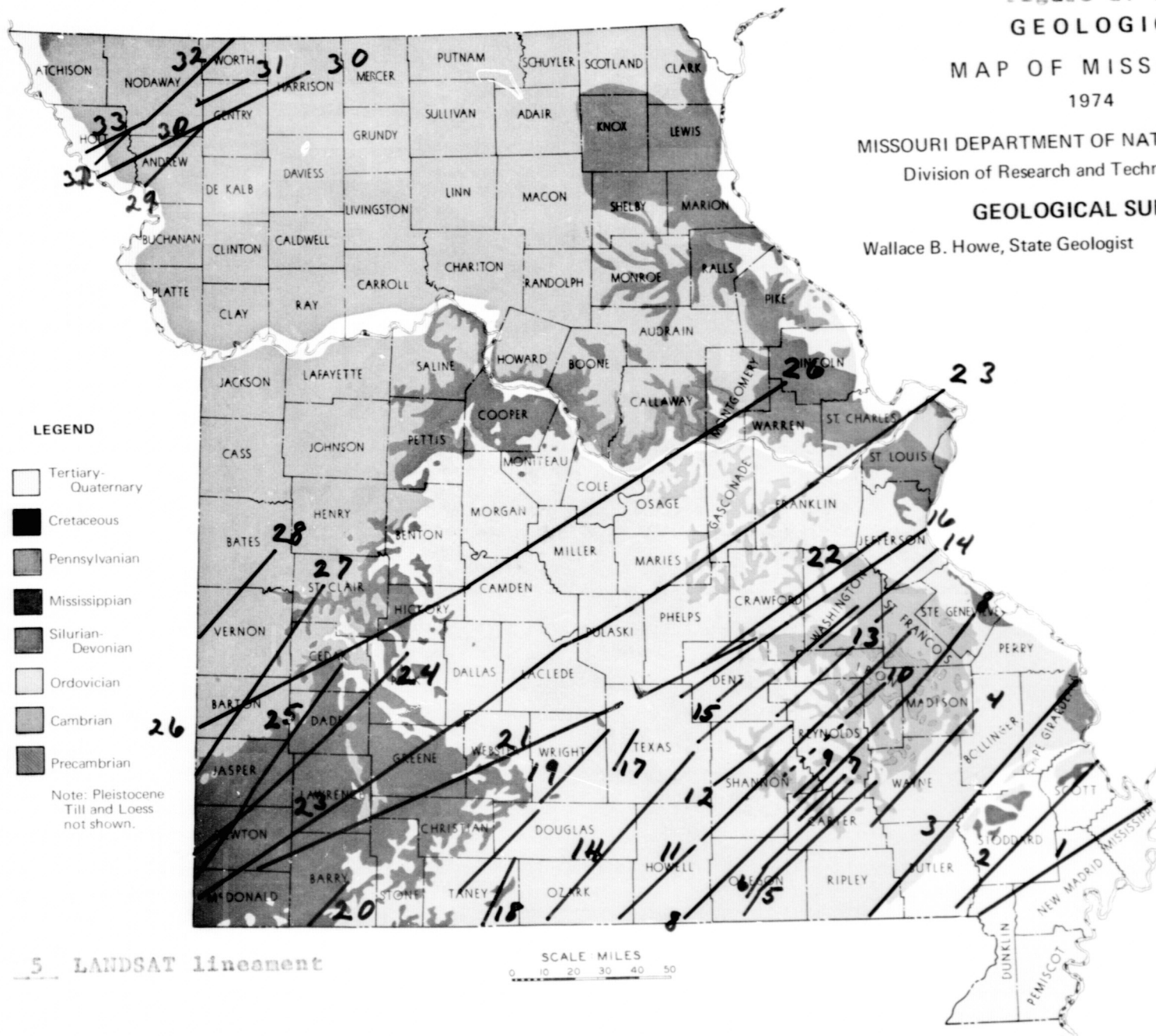
Figure IV-2  
GEOLOGIC  
MAP OF MISSOURI  
1974

MISSOURI DEPARTMENT OF NATURAL RESOURCES  
Division of Research and Technical Information

GEOLOGICAL SURVEY

Wallace B. Howe, State Geologist

Rolla, Mo.



ORIGINAL PAGE IS  
OF POOR QUALITY

Figure IV-3

GENERAL STRUCTURAL MAP  
SHOWING NE-TRENDING LINEAMENTS

MAJOR STRUCTURAL FEATURES  
OF MISSOURI

Mary H. McCracken  
1966

IV-4

Contoured on base of the  
Roubidoux Formation

Reconstructed in areas of  
complete removal of the  
Roubidoux by erosion

Contour interval 250 feet

Approximate area of complete  
removal of the Roubidoux in  
the subsurface

Area of pre-Roubidoux outcrop

Fault  
Dashed where approximately  
located. U, upthrown side;  
D, downthrown side

Anticline

LANDSAT lineament

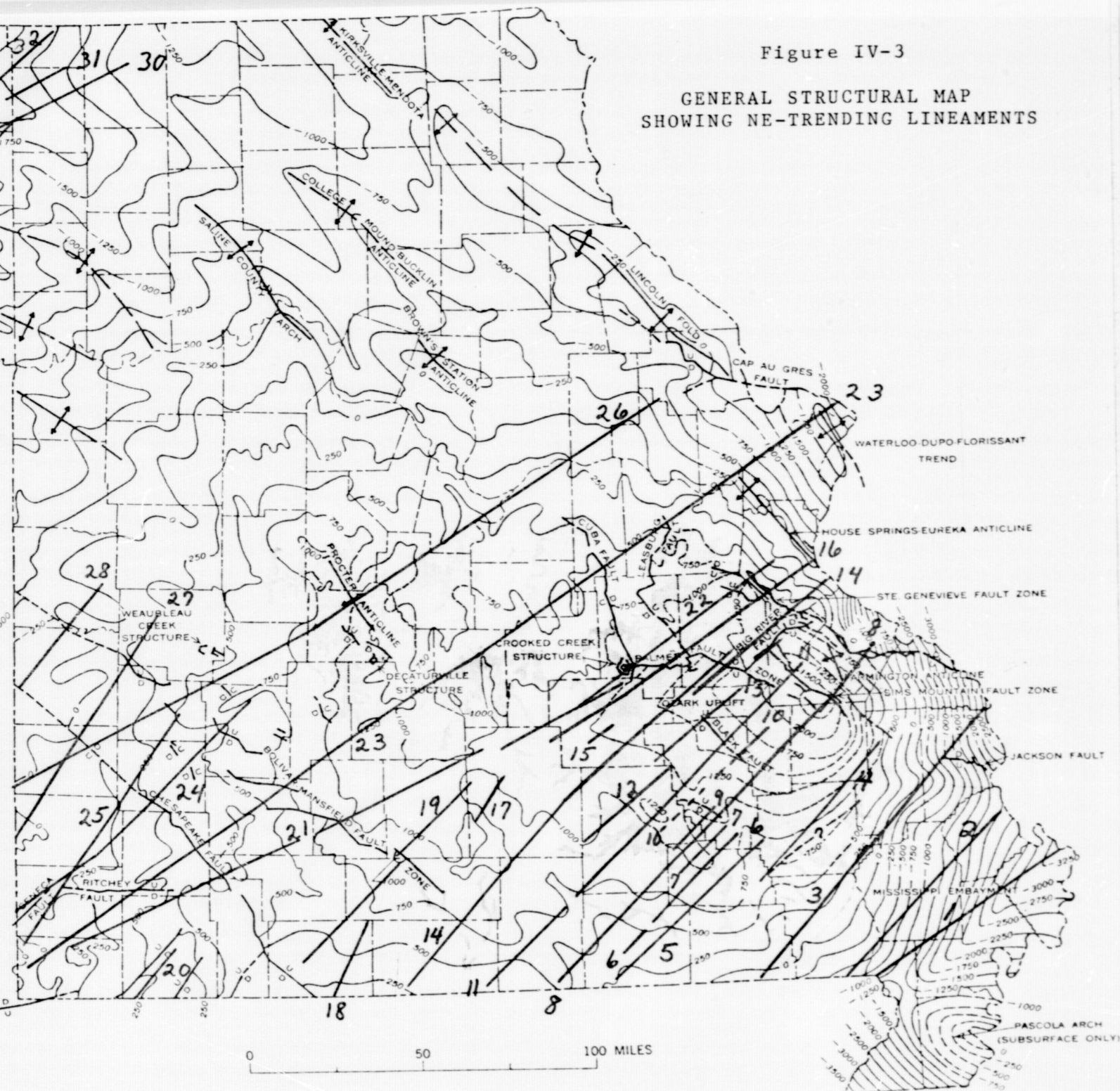
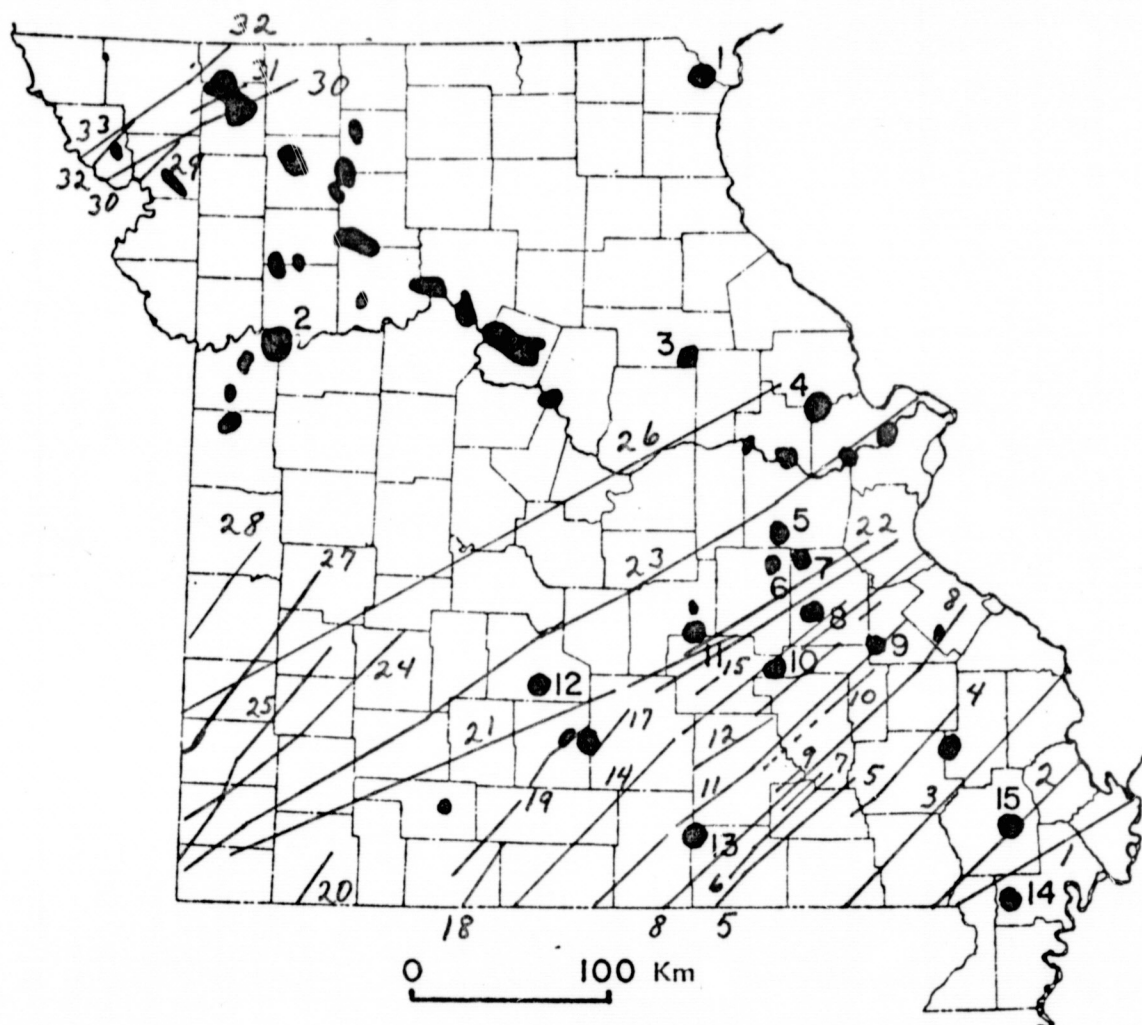




Figure IV-4

GENERAL MAGNETIC ANOMALY MAP  
SHOWING NE-TRENDING LINEAMENTS



- |                                      |                                       |
|--------------------------------------|---------------------------------------|
| 1 ST. FRANCISVILLE (mafic intrusive) | 9 IRON MOUNTAIN (iron mineralization) |
| 2 LEVASY (mafic intrusive)           | 10 BOSS (iron-copper mineralization)  |
| 3 BENTON CITY (mafic intrusive)      | 11 LAKE SPRING (iron mineralization)  |
| 4 WENTZVILLE (mafic intrusive)       | 12 ORLA (mafic intrusive)             |
| 5 KRATZ SPRING (iron mineralization) | 13 PEACE VALLEY (mafic intrusive)     |
| 6 BOURBON (iron mineralization)      | 14 MALDEN (unknown source)            |
| 7 PEA RIDGE (iron mineralization)    | 15 BLOOMFIELD (unknown source)        |
| 8 FLOYD TOWER (iron mineralization)  |                                       |

Figure IV-5

# MAJOR MINERAL COMMODITY AREAS OF MISSOURI

By W. C. Hayes and W. V. Searight

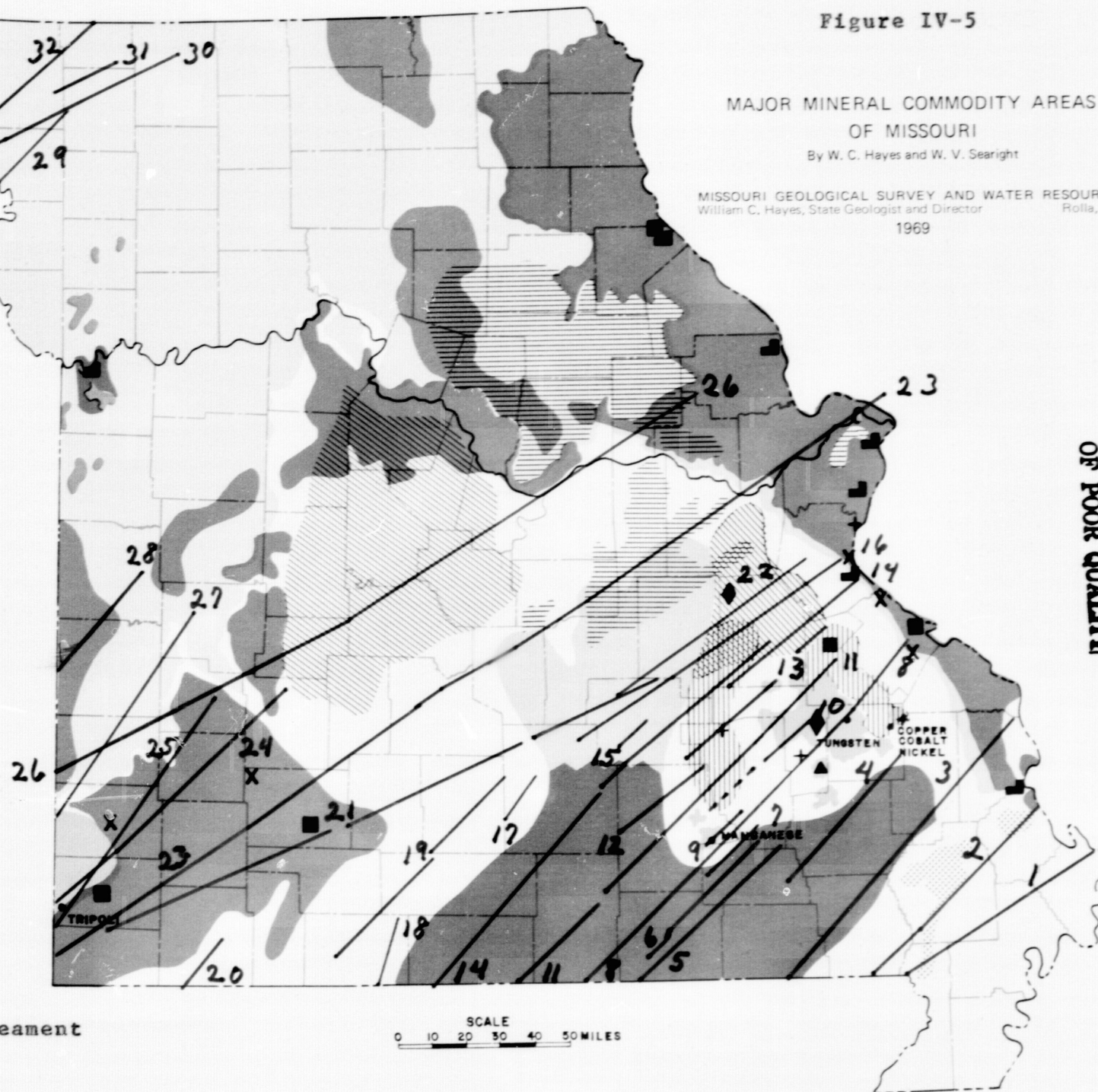
MISSOURI GEOLOGICAL SURVEY AND WATER RESOURCES  
William C. Hayes, State Geologist and Director  
Rolla, Mo.  
1969

ORIGINAL PAGE IS  
OF POOR QUALITY

## EXPLANATION

- Zinc (and lead) deposits (underground)
- Lead (and zinc) deposits (underground)
- Local sedimentary limonite surface deposits (brown iron)
- Local sedimentary hematite surface deposits (filled sink, red iron)
- Thin coal and clay - thin shale and limestone, thickens locally
- Active commercial coal stripping areas
- Local surface refractory clay deposits
- Local surface clay deposits
- Local surface b-brite deposits
- Silica sand
- Granite and porphyry
- Limestone
- Oil and gas
- Cement plant
- Lime plant
- Iron mine and pellet plant
- Roofing granule plant
- Marble
- Lead smelter
- Other local deposits

5 LANDSAT lineament



SCALE  
0 10 20 30 40 50 MILES

Arkansas line, near Campbell in Dunklin County, northeasterly to the confluence of the Mississippi and Ohio Rivers. It roughly parallels assumed fractures (faults?) shown on the Structural Features Map of Missouri (McCracken, 1971). The lineament may be an expression of a deep fault zone. Other possibilities are geographic or man-made features since portions coincide with two railroad segments. Overall, the lineament is poorly defined. Its trace, however, could be the expression of a synclisis in the buried sediments intersecting the Pascola arch. Such a feature is implied by the subsurface structural contour map of the base of the Roubidoux formation.

#2 NE Strike  $N45^{\circ}E$ ; length 106 km

The lineament, which extends from the Arkansas line near Fagus in southeastern Butler County to Commerce on the Mississippi River in northeastern Scott County, is very sharp on the imagery. For most of its extent in Missouri it coincides with the southeast-facing escarpment of Crowleys Ridge, a topographic high rising 60 meters above the embayment plain. The northeastern half of the lineament coincides with the English Hill fault, while the southwestern portion coincides with one of the traces of Fisk's Ozark escarpment fault zone. The trace is also defined by the termination of Cretaceous and Tertiary outcrops in the embayment area.

#3 NE ("Ozark Escarpment Lineament") Strike  $N43^{\circ}E$ ; length 170 km

The Ozark Escarpment defines this linear for all but the northernmost 50 km where it diverts from the escarpment to follow a nearly straight segment of a tributary to White Water River. The trace extends from the Arkansas line in south-central Ripley County northeastward to the Mississippi River at the Cape Girardeau-Perry County line. Enhancement of the trace is brought about by a sharp topographic break, change in vegetation, and outcrops of Ordovician rocks against alluvial material. The Ozark escarpment is one of the major physiographic features in the state and has been interpreted to be a fault.

#4NE ("Greenville Lineament") Strike  $N45^{\circ}E$ ; length 80 km

The linear coincides with the postulated Greenville fault which extends from the Carter-Wayne County line near Ellsinore, northeast to the Madison-Bollinger County line near Marquand. The area is blanketed by a thick cover of cherty clay residuum and evidence for the fault is based on subsurface data. Along this line are the outermost outcrops of Precambrian igneous rocks on the southeastern flank of the St. Francois Mountains. Drillhole data indicate that along portions of the lineament narrow (1-3 km-wide) grabens have developed on the buried

Precambrian surface. The Greenville lineament is believed to be the northernmost of several roughly parallel zones of structures along which a general foundering of the Platform has taken place on the northern margin of the Embayment region.

#5 NE Strike  $N48^{\circ}E$ ; length 100 km  
#6 NE Strike  $N45^{\circ}E$ ; length 80 km

The two traces located in Oregon and Carter Counties are essentially parallel. The continuation of #5 NE to the northeast would mark the southeastern edge of the major outcrop area of the St. Francois Mountain terrane. Two small zinc mines have been operated in the past in Oregon County at the south end of the traces, one in the vicinity of Alton and the other in the vicinity of Thayer. The traces converge at the south end in the area of a double circular feature. Comparison of the traces with the structural, geologic and magnetic maps gives no clue as to what they may represent. The trace of lineament #5 NE continues strongly into northern Arkansas for approximately 30 km.

#7 NE Strike  $N49^{\circ}E$ ; length 30 km  
#9 NE Strike  $N49^{\circ}E$ ; length 20 km

Two short traces parallel the "Annapolis lineament" (#8 NE). One, #7 NE, lies immediately to the southeast of #8 NE and is located in northwestern Carter and southwestern Reynolds Counties. The other is immediately to the northwest of #8 NE in Shannon, Carter and Reynolds Counties. Portions of both lineaments are coincident with segments of the Current River which is partly joint controlled. Trace #9 NE marks the southeastern edge of the Eminence block. There is drillhole evidence of basement faulting along the southeastern edge of the Eminence block along this lineament.

#8 NE ("Annapolis Lineament") Strike  $N49^{\circ}E$ ; length 225 km

The lineament extends from a short distance south of the Missouri-Arkansas line near Lanton in Howell County to the Ste. Genevieve fault system. There is no distinct evidence on the imagery examined of disruption of the trace as it crosses the fault and extends into Illinois.

The Annapolis lineament defines the southeastern boundary of the Sabula block in Iron and Reynolds Counties, and in Shannon County it is the southeastern boundary of the Eminence block. Numerous diabase dikes and sills are intruded into both the volcanic rocks and granites along this lineament in northwestern Madison County. The majority of these dikes have a  $N30^{\circ}E$  strike. The rhombic-shaped block, 11 by 11 km (7 by 7 mi) in size, defined by the Silvermine, Hogan, Ironton, and Annapolis lineaments in northeastern Iron and northwestern Madison Counties is one of the most profoundly fractured areas



in the St. Francois Mountains. A detailed air-photo analysis of this area indicates several sets of intersecting short lineaments with the most common set having a N45°E trend. Other trends measured have strikes of N17°W, N5°E, N15°E, N30°E, N65°E, and E-W.

The northeastern part of the trace in Madison and Ste. Genevieve Counties passes near Silvermines and an area of diatremes near Avon. At Avon the trace bifurcates with the new segment extending also northeasterly for a distance of 20 km and coinciding with the course of Saline River in Ste. Genevieve County. Part of the main trace, northeast of the point of bifurcation, lies along a weak magnetic lineament. In the buried basement of southwestern Ste. Genevieve County, a mafic igneous body has been emplaced along the magnetic lineament, as indicated by one drillhole. Areas of mineralization along the linear are located at Annapolis, Iron County (inactive lead mines); Silvermine, Madison County, an area of tungsten, lead and cassiterite mineralization (inactive mine) and lead prospects near Avon in southwestern Ste. Genevieve County. In the Avon area a cluster of Devonian alnoite-kimberlite dikes is present.

#10 NE ("Hogan Lineament") Strike N48°E; length 75 km

The "Hogan lineament" is defined on the basis of outcrop patterns of igneous rocks, air-photo analysis and aeromagnetic data. It is seen as a discontinuous lineament, composed of straight and slightly offset curvilinear segments extending from near Eminence in Shannon County to Ironton, Iron County. A portion of straight southwestern segment defines the northwestern boundary of the Sabula block. A series of faults mapped on Hogan Mountain (R. E. Anderson, 1970) may be related to this lineament. In the Iron County segment, particularly to the east of Ironton, the lineament is most strongly expressed by a marked and persistent alignment of topographic features visible on air photos. At the southwestern end in Shannon County the lineament appears to be one of the northwestern boundary faults of the Eminence Block. The "Hogan lineament" terminates at Ironton against the northwestern-trending Ironton fault. The trace also marks the southeastern flank of the Taum Sauk caldera and crosses the northwestern-trending Ellington and Black River faults without any apparent offset.

#11 NW ("Stono Lineament") Strike N47°E; length 220 km

The "Stono lineament" extends from the Arkansas line at Norfork Reservoir in southeastern Ozark County to the St. Francois-Ste. Genevieve County line. The trace can be observed on the imagery extending 100 km into northern Arkansas. The lineament is defined as a series of parallel faults in the granite outcrop on Stono Mountain in southwestern

St. Francois County. To the southwest, it defines the southeastern boundary of the Belleview block and the northwestern boundary of the Taum Sauk caldera. In northern Shannon County, it may form one of the boundary faults of the Eminence block where basement rocks are sheared and strongly altered. Several diabase dikes have been mapped along the lineament (Tolman & Robertson, 1969).

The "Stono lineament" crosses both the Ellington and Black faults. Where it crosses the Ellington fault, there is a change in the strike of the fault from a west-northwestern to a northwestern direction. Unlike the "Hogan lineament", the "Stono lineament" crosses the Ironton fault and continues northeastward, terminating in the Simms Mountain Fault System in the area of the east-west "38th parallel lineament" (#5 EW) near the St. Francois-Ste. Genevieve County line. The "Stono lineament" marks the southeastern edge of the Graniteville granite outcrop, and the trace passes through the center of the Taum Sauk caldera. It coincides with the Stono Mountain faults near its northeastern terminus.

In comparison with the ground magnetics, the lineament lies at the northwestern edge of the Peace Valley anomaly, northeast of West Plains. Mineralization exists along the lineament in the area of the Caulfield zinc-lead-pyrite deposits at its southwestern end. It also marks the southeastern edge of the Viburnum Trend as well as the southeastern edge of the Flat River-Bonneterre-Farmington "Old Lead Belt" district. The general area between the "Stono" and "Annapolis" (#8 NE) lineaments is weakly mineralized. The trace also passes through the Eminence area of minor copper mineralization. The "Stono lineament" exemplifies the case that the lineaments observed on the LANDSAT imagery are zones and not single lines or traces.

#12 NE Strike N52°E; length 52 km

The trace extends from the Shannon-Texas County line, south of Summersville, to the northeastern corner of Shannon County, south of Bunker. The trace crosses the Ellington fault and terminates a short distance beyond. A large portion of the trace coincides with two tributaries of the Current River, Spring Valley Creek and Big Creek. Drillholes indicate a possible basement fault along this lineament in northeastern Shannon County.

#13 NE ("North Belleview Lineament") Strike N50°E; length 85 km

The lineament extends from southeastern Dent County to Bonne Terre in north-central St. Francois County. The lineament is parallel to the "Boss-Potosi lineament" (#14 NE)



which is about 13 km to the northwest. The northeastern segment of the "North Belleview lineament" is defined by the sharp topographic escarpment of Logan Mountain in northern Iron County and marks the northwestern boundary of the Belleview block. It is extended southwestward to the "Black River lineament" (#13 NW) on the basis of alignments in drainage patterns visible on air photos. Aeromagnetic maps also indicate the lineament and suggest that it may continue farther southwestward for a distance of at least 9.6 km into northern Reynolds County. There is a slight offset to the north past its intersection with the "Black River lineament" (#13 NE). Drillholes indicate that basement rocks along this segment of the lineament are severely sheared, fractured and mylonitized. An aeromagnetic lineament in northern Shannon County has the same trend as the "North Belleview lineament" and may indicate its continuation to the southwest.

At the northern end, in Washington County, there is an offset of some 3 km to the northeast where the lineament crosses the Cedar Creek fault. The offset segment lies just to the southeast of the main trace of the Big River fault, the northeastern leg of the Palmer Fault System, and appears to coincide with the southeastern terminus of several very short northwest-trending faults or fractures that may be part of the northwest-trending Simms Mountain Fault System which also terminates at the Big River fault. The small tear faults are at an angle to the northeast-southwest trending Big River fault. The short offset northeastern segment of the "North Belleview lineament" lies essentially at the northwestern edge of the Flat River-Bonneterre lead district. Immediately to the northwest of the structure is the Washington County barite district which includes minor lead/zinc mineralization.

#14 NE ("Boss-Potosi Lineament") Strike N47°E; length 275 km

The lineament extends from the Arkansas line at the North Fork of Bull Shoals Lake in southwestern Ozark County to the Mississippi River in southern Jefferson County. The trace continues for more than 70 km into northern Arkansas but does not appear to cross the Mississippi River into Illinois. At the Missouri-Arkansas border the trace lies along one arm of Bull Shoals Lake for a distance of 10 km. It also coincides with portions of North Big Creek, a tributary of the Current River. The lineament can be separated into two segments -- a northeastern segment with a strike of N48°E and a length of 155 kms and a 120-km southwestern segment with a strike of N42°E. The trace crosses the east-west Palmer fault system and the northwest-southeast trending Valle Mines-Vineland fault zone. In comparison with the geology of the area, nothing exceptional appears nor are there distinctive changes associated with the trace. A comparison with the ground magnetic maps shows that the northeastern leg passes through the Boss anomaly and there

is a faint suggestion of a magnetic linear extending along the trace from Boss to Potosi, a distance of some 50 km. The major areas of mineralization on the trace are the Boss anomaly and where it intersects the Viburnum Trend lead district.

Interestingly, the southwestern segment is the stronger trace from the Missouri line northward. It coincides with drainage segments but apparently does not reflect structure, magnetics or bedrock geology.

#15 NE Strike  $N49^{\circ}E$ ; length 30 km

A very short linear located in south-central Dent County and striking  $N49^{\circ}E$ . Comparison with major drainage systems, structure, bedrock geology, mineral deposits and magnetics shows no apparent relationship.

#16 NE Strike  $N58^{\circ}E$ ; length 150 km

The lineament extends from Licking in northeastern Texas County to the Mississippi River at Herculaneum in Jefferson County. It crosses the Berryman fault in Crawford County, where the fault changes strike from nearly east-west to northwest. Other faults crossed are the Aptus in Washington County, and the Valles Mines-Vineland fault zone in Jefferson County where some of the fault segments coincide with the trace. Drillholes indicate a basement fault crossing the Crawford-Washington County line along this lineament. The lineament marks the southeastern margin of the northernmost Precambrian outcrops in Missouri along the northeastern extension of the basement fault. Northeast of the Valles Mines fault, the trace coincides with Joachim Creek and Missouri Highway 21A. South of the Valles Mines-Vineland fault it coincides with segments of the Mineral Fork, Fourche and Renault tributaries of Big River. The southern portion of the trace marks the approximate northwestern boundary of the "Salem Basin", a magnetic low which is probably floored by granite. The trace passes through the Washington County barite district which also contains some minor zinc and lead mineralization.

#17 NE Strike  $N32^{\circ}E$ ; length 25 km.

A short trace in west-central Texas County shows no relationship to any known structure or unusual bedrock features. At the southeastern end, there is a small area of zinc mineralization north of Mountain Grove. In comparison with the magnetic map, the linear appears to follow the southeastern margin of the Dawson anomaly on the Texas-Wright County line.

#18 NE Strike  $N27^{\circ}E$ ; length 50 km

The trace, present in southeastern Taney County, extends from the Arkansas line to the northeastern corner of the county. The trace extends into northern Arkansas for a distance of 35 km, giving it a total length of 85 km. There are no known structures, mineralization or significant geologic features associated with the lineament.

#19 NE ("Mansfield Lineament") Strike  $N46^{\circ}E$ ; length 85 km

The lineament is composed of two segments and extends from near Forsyth in central Taney County to the Wright-Texas County line, northeast of Rayborn. The offset of the lineament takes place near Mansfield in southwestern Wright County, where the trace crosses lineaments #26 NW and #28 NW. The northern segment crosses the southern part of the Mansfield Fault System. The southern part of the lineament follows a small tributary of Beaver Creek in Douglas County and crosses several small inactive zinc-mining areas. The trace passes between two magnetic anomalies in Wright County and marks the northwestern flank of the previously cited Dawson anomaly.

#20 NE ("Roaring River lineament") Strike  $N38^{\circ}E$ ; length 30 km

The lineament is located in south-central Barry County and extends from the Arkansas line near Seligman to Mineral Spring. The trace parallels the Eagle Rock fault to the east and the Greasy Creek fault to the west, as well as the axis of the Washburn syncline which also lies immediately to the west. It is thought the trace might represent additional unmapped faults or fractures in the area.

#21 NE Strike  $N65^{\circ}E$ ; length 290 km

The lineament extends from northern McDonald County near Goodman in the southwestern corner of the state, northeast to the Dent-Crawford County line near Sligo. The trace crosses a number of northwest trending faults and lineaments, but there are no known structures lying along the trace itself. There are several small zinc-lead deposits along the trace, including the Aurora (Lawrence County) and Pearson Creek (Greene County) zinc-lead deposits, neither of which have been active for many years.

#22 NE Strike  $N57^{\circ}E$ ; length 120 km

The lineament extends from Lenox in northwestern Dent County to Hillsboro in Jefferson County. It crosses the

Crooked Creek cryptoexplosive structure in southwestern Crawford County and the northwest-striking Valles Mines-Vineland fault zone in Jefferson County. It marks the northern edge of a northeast-trending Precambrian topographic high; crosses through the Indian Creek lead-zinc mine, and follows the Cambro-Ordovician contact northeast of the mine.

#23 NE ("Lebanon Lineament") Strike  $N56^{\circ}E$ ; length 460 km

The lineament extends across the state from near the Oklahoma line in southwestern McDonald County to the Mississippi River near its junction with the Missouri River. The lineament is composed of three segments with slight changes of strikes with the northeastern segment following the Missouri River. A pronounced linear magnetic high coincides with the "Lebanon lineament" in St. Louis and St. Charles Counties. Several circular features are aligned along the central and southwestern portions of the lineament, including the Hazelgreen cryptoexplosion structure in Laclede County.

#24 NE ("Seneca lineament") Strike  $N46^{\circ}E$ ; length 145 km

The trace extends from Seneca on the Oklahoma line in southwestern Newton County to north-central Polk County. It also extends 20 km into Oklahoma, giving it a total length of 165 km. The lineament defines the trace of the Seneca fault in Southwest Missouri; it crosses the Joplin asymmetrical anticline in Jasper County and follows segments of White Oak Creek in Jasper and Lawrence Counties and an arm of Stockton Lake in Dade County. The small Dadeville zinc subdistrict in Dade County lies on the lineament, as does the southern end of the Joplin zinc-lead district. In Oklahoma, several north-east-aligned zinc-lead deposits lie on the trace.

#25 NE Strike  $N35^{\circ}E$ ; length 135 km

The trace extends from the Oklahoma line in northwestern McDonald County to near Stockton in central Cedar County. It continues into Oklahoma for 20 km, giving a total length of 155 km. The trace crosses the Joplin and Golden City-Miller anticlines and terminates at the Stockton fault, a part of the Bolivar-Mansfield Fault System. There is no known faulting lying along the trace itself. Major mineralization is the Joplin zinc-lead district along the southern part of the lineament.

#26 NE ("Osage Lineament") Strike  $N62^{\circ}E$ ; length 340 km

The lineament extends from the Kansas line in southwestern Barton County to near Hawk Point in southwestern

Lincoln County. It strikes N55°E and crosses the state near its geographical center just south of Jefferson City. Part of the Missouri River follows the lineament. The trace crosses a number of structures but there are no known structures lying along it. The lineament follows a small magnetic anomaly in Cedar County and crosses the Central barite district.

#27 NE Strike N31°E; length 100 km

The trace extends from the Kansas line in west-central Jasper County to southwestern St. Clair County, north of El Dorado Springs. It also continues southwest into Kansas and Oklahoma for an additional 70 km. The lineament crosses several northwest-striking faults, anticlines and synclines but there are no known northeast-trending structures lying along its trace in Missouri. Its extension into Kansas and Oklahoma indicates it may coincide with the Miami shear trough. A segment of the trace is along Spring River near the state line.

#28 NE Strike N40°E; length 60 km

The linear extends from the Kansas line in west-central Vernon County to east-central Bates County. It crosses several northwest-striking folds and faults but does not coincide with any known structures. The southern portion of the trace is in juxtaposition and parallel to a segment of the Missouri Pacific Railroad.

#29 NE Strike N47°E; length 45 km

The trace extends from the Missouri River (state line) in southwestern Andrew County to near Stanberry in western Gentry County. The lineament crosses the "Nodaway structure" near the confluence of the Nodaway River with the Missouri River on the Andrew-Holt County line and terminates against the northeast-trending Lineament #29 NE at approximately the mapped axis of the northwest-trending Hamilton-King City-Quitman anticline. The southwestern end of the linear lines up with a major deflection or direction change of the Missouri River drainage from southeast to northeast. In addition to the Nodaway structure at the southwestern end of the linear, it also passes through a circle trace observed on the LANDSAT imagery at its northeastern end.

#30 NE Strike N65°E; length 150 km

The lineament extends from the Missouri River in southern Holt County to north-central Harrison County. The linear lies

on the northwestern flank of a magnetic anomaly (Curzon) located in southern Holt County and passes through a broad, flat magnetic anomaly in the area of Fillmore in northwestern Andrew County. In central Gentry County, the linear passes between two peaks of a double magnetic anomaly. The lineament crosses essentially through the Fillmore structure, a small domal or anticlinal feature in Andrew County. The northeasternmost 10 km of the lineament lie along the stream course of Panther Creek.

#31 NE Strike  $N61^{\circ}E$ ; length 35 km

A short linear in northwestern Gentry County extends from Clyde, in eastern Nodaway County, northeast to Denver, in southern Worth County. It passes through a low between two of the magnetic anomalies in northwestern Gentry County.

#32 NE Strike  $N46^{\circ}E$ ; length 100 km

The linear extends from the Missouri River near Forest City in southern Holt County to the Iowa line near Irena in north-central Worth County. Several bedrock highs lie along the linear where it crosses the Nodaway and 102 Rivers, indicating the linear might reflect the axis of a northeast-southwest anticlinal structure. It lies on the southeastern flank of a magnetic anomaly in east-central Holt County and roughly separates it from a rather broad, low magnetic high in northwestern Andrew County.

#33 NE Strike  $N60^{\circ}E$ ; length 30 km

A short linear in central Holt County extends from the Missouri River to the Holt-Andrew County line, where it intersects #32 NE. No apparent structural relationships to the trace.

## 2. Northwest-Trending Lineaments

Thirty northwest-trending lineaments have been observed and numbered. Several are 300 to 400 km long and extend from the southeastern part of the state into northern Missouri. Some of the prominent lineaments are expressed on the ground as geomorphic features, such as the valley of the Grand River in northwestern Missouri which also continues on strike with a segment of the Missouri River in central Missouri. Most of the major lineaments coincide with a number of geologic features and magnetic anomaly trends. A major lineament was traced from Mexico, Missouri southeast to the New Madrid seismic area, intersecting the lineaments of the Reelfoot rift. These and other major lineaments intersect or are parallel with known mineralized areas. Figures IV-6 thru IV-10 show the relationship of the northwest-trending lineaments with the relief, general geologic setting, major structural features, magnetic anomalies and principal mineral resource areas in the state.

#1 NW ("Lincoln Fold Lineament") Strike  $N40^{\circ}W$ ; length 100 km

The lineament extends from southeastern Lincoln County near Winfield to Renesselaer at the Ralls-Marion County line. The trace essentially follows the axis of the Lincoln Fold from the Cap au Gris fault in southern Lincoln County northwestward to a point west of Hannibal, Marion County. The Lincoln Fold is an asymmetrical anticline striking  $N45^{\circ}$  with steeper dips on the SW flank which also is an area of some local faulting. The axis of the fold is mapped 75 kms beyond the point at which the LANDSAT trace terminates. Relief on the Lincoln Fold is estimated at a maximum of 300 meters. The lineament roughly corresponds to the axis of a buried basement high of rhyolitic volcanic rocks.

#2 NW Strike  $N41^{\circ}W$ ; length 35 km

A short trace extends between Auburn in central Lincoln County and Bowling Green in central Pike County. For a distance the southern part of the trace lies along the Cap au Gris fault in central Lincoln County.

#3 NW Strike  $N57^{\circ}W$ ; length 435 km

The trace starts at the Mississippi River in the southern part of St. Louis County and extends northwestward to the Iowa line in the northeastern corner of Worth County. The trace intersects the House Springs-Eureka anticline near New Melle in western St. Charles County where an anticlinal structure is



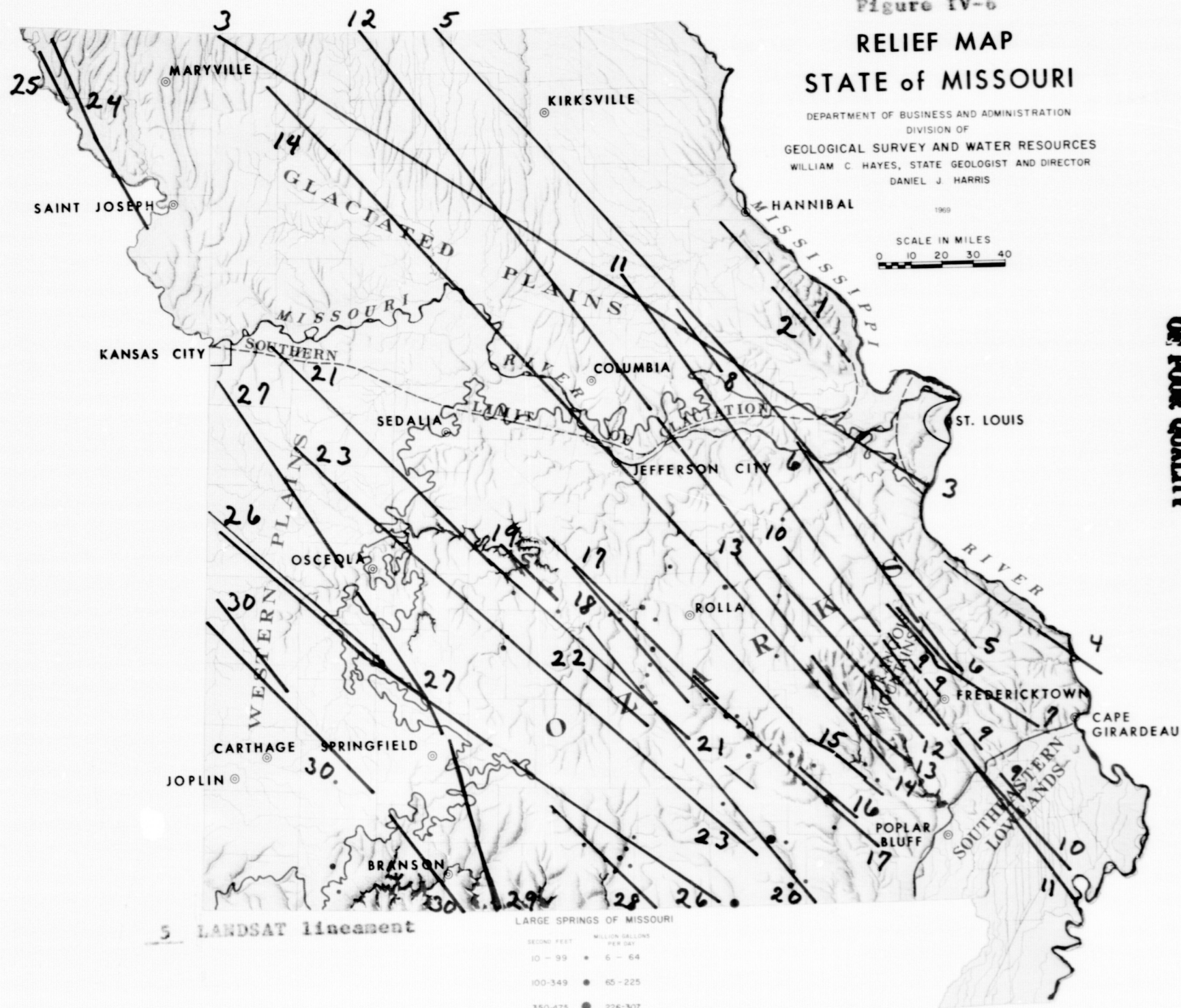
Figure IV-6

# RELIEF MAP STATE of MISSOURI

DEPARTMENT OF BUSINESS AND ADMINISTRATION  
DIVISION OF  
GEOLOGICAL SURVEY AND WATER RESOURCES  
WILLIAM C. HAYES, STATE GEOLOGIST AND DIRECTOR  
DANIEL J. HARRIS

1969

SCALE IN MILES  
0 10 20 30 40



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OF POOR QUALITY

IV-16

Figure IV-7

GEOLOGIC

MAP OF MISSOURI

1974

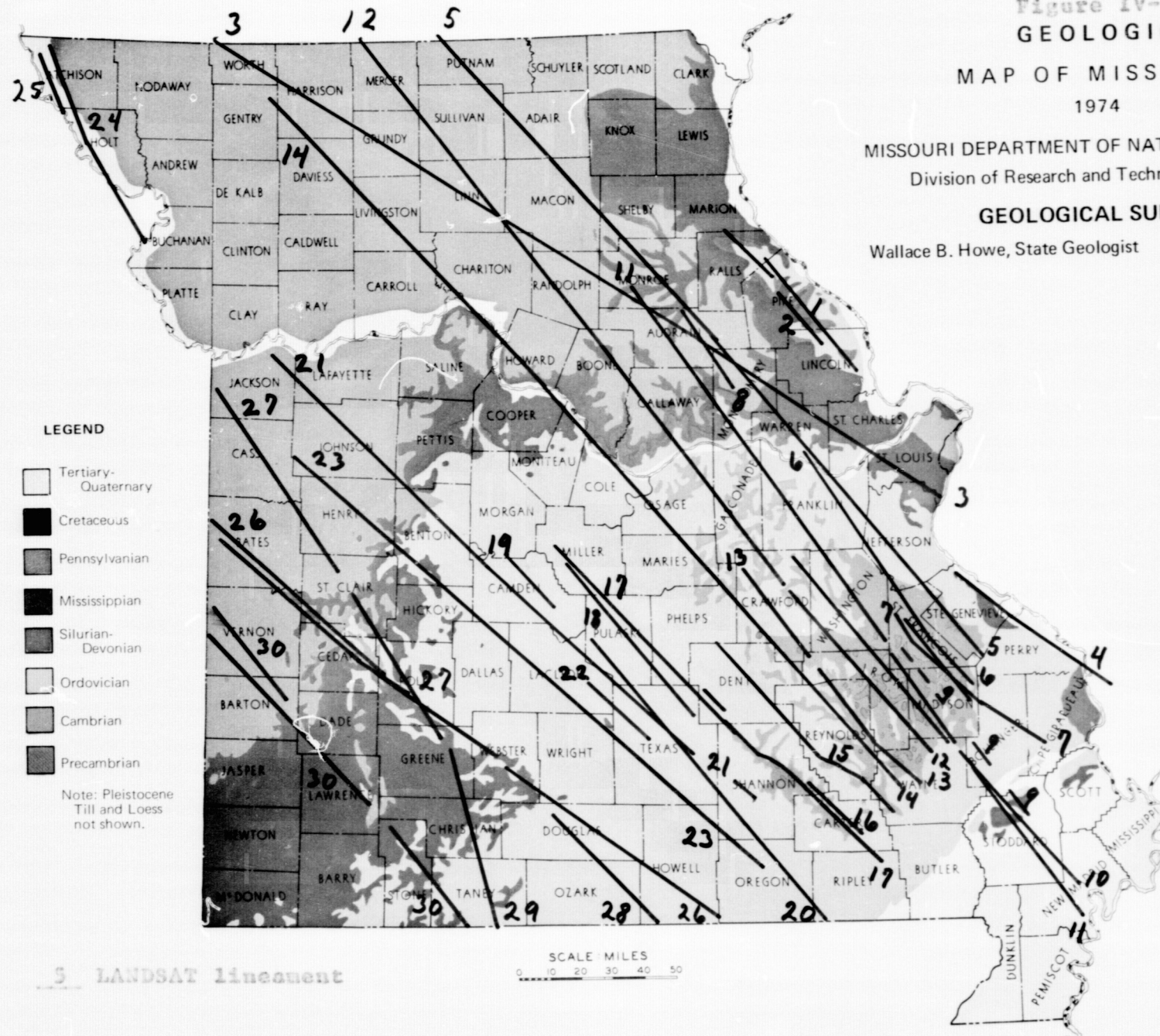
MISSOURI DEPARTMENT OF NATURAL RESOURCES

Division of Research and Technical Information

GEOLOGICAL SURVEY

Wallace B. Howe, State Geologist

Rolla, Mo.



5 LANDSAT lineament

SCALE MILES  
0 10 20 30 40 50

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IV-19



Figure IV-8  
MAJOR STRUCTURAL FEATURES  
OF MISSOURI

Mary H. McCracken  
1966

IV-20

- Contoured on base of the Roubidoux Formation
- - - Reconstructed in areas of complete removal of the Roubidoux by erosion

Contour interval 250 feet

- Approximate area of complete removal of the Roubidoux in the subsurface
- Area of pre-Roubidoux outcrop
- Fault  
Dashed where approximately located. U, upthrown side; D, downthrown side
- Anticline

5 LANDSAT lineament

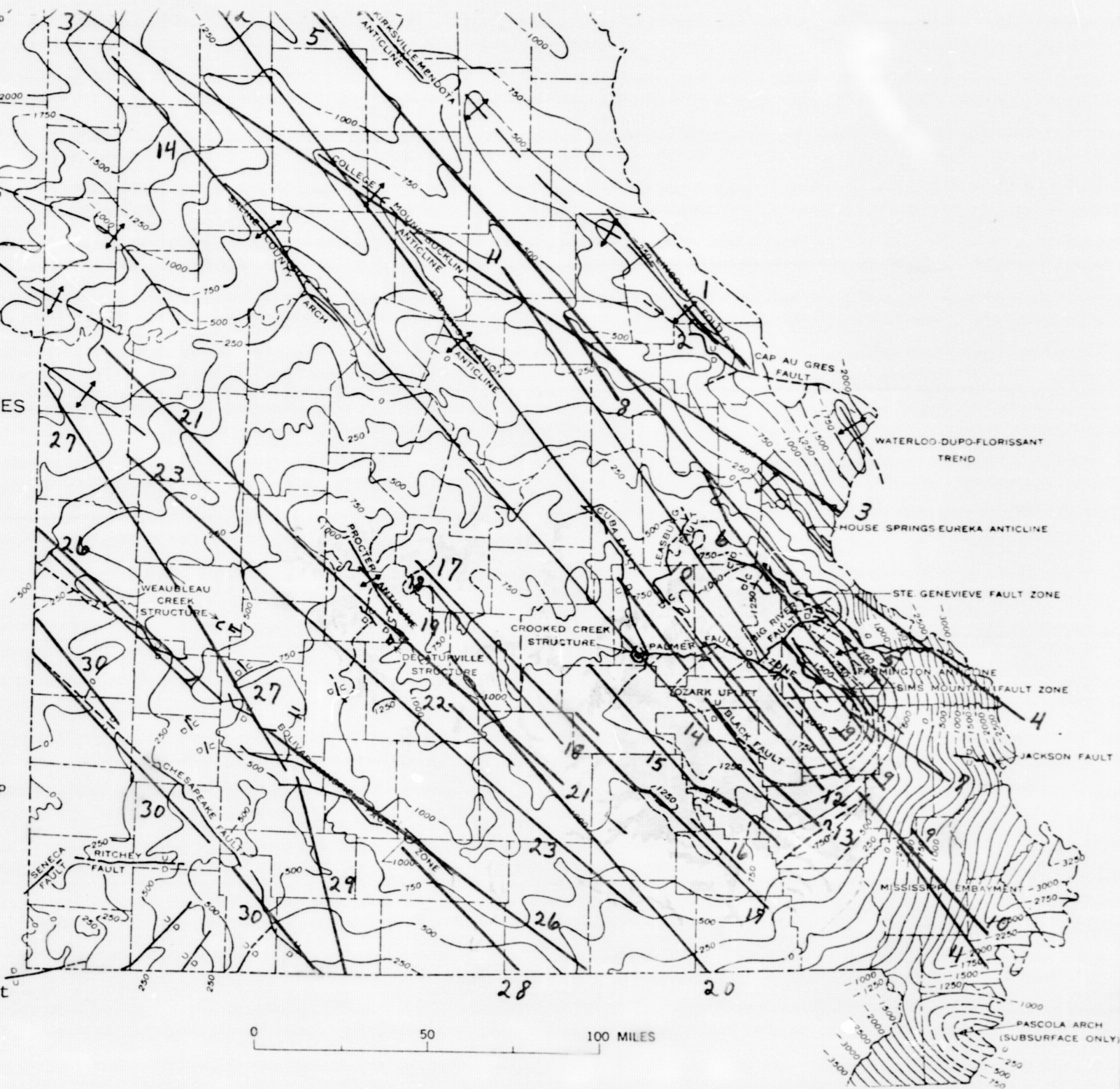
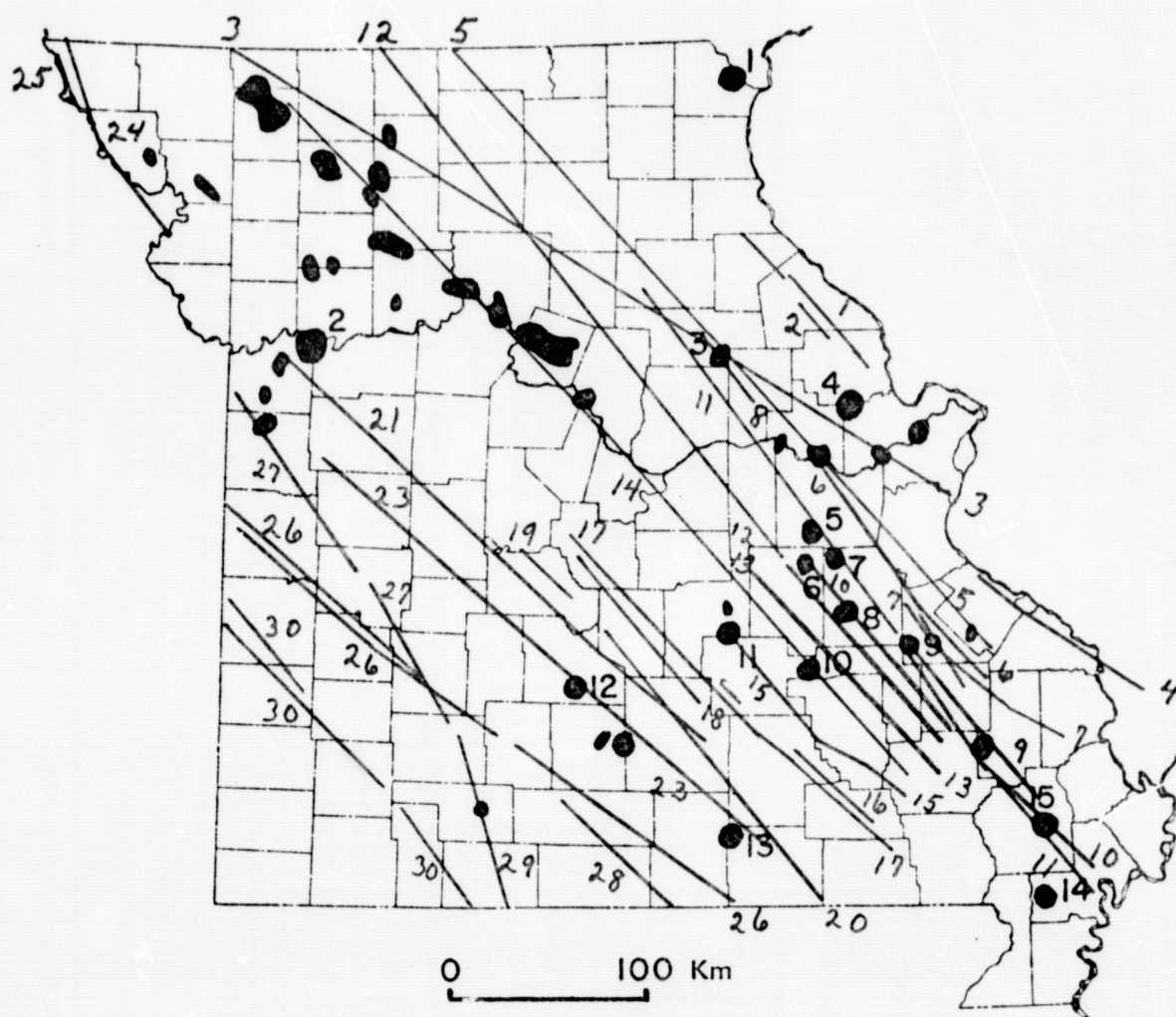


Figure IV-9  
GENERAL MAGNETIC ANOMALY MAP  
SHOWING NW-TRENDING LINEAMENTS



- |                                      |                                       |
|--------------------------------------|---------------------------------------|
| 1 ST. FRANCISVILLE (mafic intrusive) | 9 IRON MOUNTAIN (iron mineralization) |
| 2 LEVASY (mafic intrusive)           | 10 BOSS (iron-copper mineralization)  |
| 3 BENTON CITY (mafic intrusive)      | 11 LAKE SPRING (iron mineralization)  |
| 4 WENTZVILLE (mafic intrusive)       | 12 ORLA (mafic intrusive)             |
| 5 KRATZ SPRING (iron mineralization) | 13 PEACE VALLEY (mafic intrusive)     |
| 6 BOURBON (iron mineralization)      | 14 MALDEN (unknown source)            |
| 7 PEA RIDGE (iron mineralization)    | 15 BLOOMFIELD (unknown source)        |
| 8 FLOYD TOWER (iron mineralization)  |                                       |



Figure IV-10

# MAJOR MINERAL COMMODITY AREAS OF MISSOURI

By W. C. Hayes and W. V. Searight

MISSOURI GEOLOGICAL SURVEY AND WATER RESOURCES  
William C. Hayes, State Geologist and Director  
Rolla, Mo.  
1969

## EXPLANATION

- Zinc (and lead) deposits (underground)
- Lead (and zinc) deposits (underground)
- Local sedimentary limonite surface deposits (brown iron)
- Local sedimentary hematite surface deposits (filled sink, red iron)
- Thin coal and clay - thin shale and limestone, thickens locally
- Active commercial coal stripping areas
- Local surface refractory clay deposits
- Local surface clay deposits
- Local surface barite deposits
- Silica sand
- Granite and porphyry
- Limestone
- Oil and gas
- Cement plant
- Lime plant
- Iron mine and pellet plant
- Roofing granule plant
- Marble
- Lead smelter
- Other local deposits

5 LANDSAT lineament

SCALE  
0 10 20 30 40 50 MILES

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postulated to extend westward through central Warren and Montgomery Counties. The trace coincides with the axis of the postulated anticline for a distance of 25 kms. In the vicinity of Mexico in central Audrain County, the trace crosses the northeast-southwest-striking Mexico anticline at nearly right angles and lies just to the southwest of the College Mound-Bucklin anticline which has a map trace of 65 km. The trace parallels the Trenton anticline, lying just to the north of the mapped axis, and at its northernmost portion coincides with the mapped axis of the structure. It is possible that the LANDSAT trace lies along the axes of these anticlines. In Linn County, the trace lies essentially on the Browning-Purdin structure, one of several little-understood structures of steeply-dipping, downwarped Pennsylvanian rocks present in the state.

From southern St. Charles County to just east of Moberly in Randolph County, a distance of 160 km, the trace follows a significant topographic break.

To the southwest the land lies at an elevation of 240 to 310 meters; to the northeast it has an altitude of 180 to 245 meters above sea level. This portion of the trace also marks the approximate boundary between the eastern and northeastern drainage to the Mississippi River and the southern and southeastern drainage to the Missouri River. Along its entire length portions of the trace coincide with a number of stream segments.

Three magnetic highs are present along the lineament. At the southeastern end, the trace passes through the "Defiance anomaly" in St. Charles County; through a "saddle" in the Benton City anomaly in Audrain County; and in central Grundy County it lies on the southwestern flank of a low, flat-topped anomaly. The lineament passes through the Northern Fireclay district (refractory clay) and the Bevier coal field, but there is no apparent relationship of the trace to the boundaries of either.

#4 NW Strike  $N54^{\circ}W$ ; length 75 km

A short trace parallels the Mississippi River in the southeastern part of the state in Perry and Ste. Genevieve Counties. The southern portion of the trace lies along the Ste. Genevieve fault system for approximately 35 kms in Perry County from Wittenberg to McBride where the direction of the fault system changes from northeast to essentially east-west.

North of McBride to St. Marys the trace more than likely reflects a portion of the St. Louis-San Francisco Railroad and Mississippi River bluff from St. Marys northward to the Ste. Genevieve-Jefferson County line where the trace can no longer be distinguished. Neither the magnetic map nor the

minerals map show any major associations with the trace. Major relationship is its coincidence with the Ste. Genevieve fault system from where it enters Missouri at Wittenburg to McBride.

#5 NE Strike N42°W; length 440 km

The lineament extends from southwestern Perry County to the Iowa line in northwestern Putnam County. In western Ste. Genevieve and eastern St. Francois Counties the trace lies along the northeast flank of a large outcrop area of Cambrian Lamotte Sandstone (Jonca Creek block) and small outcrops of Precambrian intrusives, and between the northwest-southeast trend of the Ste. Genevieve fault system and the axis of the Farmington anticline. Where it crosses the Missouri River, the trace coincides with a short northwest-southeast segment of the river. Further to the north the linear lies approximately 15 km to the east of the Macon-Sullivan trough and parallels the mapped axis of this structure through Macon, Adair and Sullivan Counties for a distance of 110 km.

The lineament passes through an anomaly in southern Warren County and lies on the northeastern flank of the Benton City anomaly in Audrain County. Metallic mineralization (lead and zinc) is present at the southern end of the trace near Silver Lake in Perry County, Avon in southern Ste. Genevieve County and Valles Mines in southern Jefferson County.

#6 NW ("Valles Mines Lineament") Strike N36°W; length 150 km

The linear extends from northwestern Bollinger County to the vicinity of Marthasville in southeastern Warren County. At its southern end the trace coincides with an eastern segment of the Mine La Motte fault in Madison County and along its central portion it coincides with a 25-km segment of the Valles Mines-Vineland fault zone in southwestern Jefferson County.

The trace ends on a magnetic anomaly centering near Marthasville in southern Warren County. It marks the northeastern flank of the Flat River-Bonne Terre-Farmington "Old Lead Belt" area, and the Higdon ore body in western Perry County lies at the southern end of the trace.

#7 NW ("Simms Mtn. Lineament") South segment Strike N56°W; length 50 km. North segment Strike N42°W; length 50 km

A dog-leg trace extends from near Gordonville in western Cape Girardeau County to northwestern St. Francois County, west



of Bonne Terre. Change in strike direction takes place just east of Fredericktown in northeastern Madison County. The northern segment of the lineament coincides with the Simms Mountain fault system, a major structure lying on the northeastern flank of the outcrop area of Precambrian volcanics and intrusives. Along the lineament's trace in northeastern Madison County, drillholes indicate a basement fault. The southernmost portion of the trace lies along a stream drainage. The Scopus structure, an area of highly disturbed Ordovician, Devonian and Cretaceous rocks and the Coal Mine fault are near the southern end of the trace. The lineament terminates at the junction of the Simms Mountain fault system with the northeast-southwest trending Big River fault in St. Francois County. The trace passes through the Flat River and Fredericktown lead districts but terminates before going into the Washington County barite district.

#8 NW Strike N31°W; length 55 km

A very short lineament extends from the Big Springs anticline in Montgomery County to an area near Rush Hill in central Audrain County. The only structure on the trace is the northwest-striking Big Springs anticline at the southern end. The lineament roughly parallels the Mineola anticlinal structure which lies some 5 to 7 km to the west. The trace crosses the Benton City anomaly in southeastern Audrain County.

#9 NW Strike N36°W; length 115 km

The trace begins in the embayment region in northern Stoddard County and terminates at the Stono Mountain fault along the southernmost of the two "38th Parallel lineaments" near Bismarck in southwestern St. Francois County. The southern 30 km of the trace lie in the Mississippi Embayment or "Bootheel" portion of the state. It can be seen extending across the alluvial plains, Crowleys Ridge, a topographic high of Cretaceous-Tertiary rocks, and across the Ozark Escarpment into the Ozark Upland. The trace can also be followed across the outcrop belt of Middle Ordovician through Lower Ordovician, Upper Cambrian and Precambrian outcrops. The trace coincides with some drainage patterns in the Embayment region as well as segments of other drainageways in the uplands. The lineament coincides with a series of magnetic lows between Silver Mine and the Cottoner Mountain magnetic high. Southeast of Cottoner Mountain, it coincides with a probable basement fault. The trace passes near Silver Mines, an area of lead, tungsten and tin mineralization in northwestern Madison County, and through the "Marquand circle" in southeastern Madison County.

#10 NW ("Ironton lineament") South segment Strike N42°W;  
length 85 km. North segment Strike N38°W; length 150 km

With a total length of 235 km, the trace extends from the Mississippi River at New Madrid to Interstate 70 (US Hwy 66) between Bourbon and Sullivan in northern Crawford County. The change in direction takes place where it crosses the Ozark Escarpment (#3NE) and also lineament #11 NE. In the Embayment area the trace coincides with the Castor River in Stoddard County, and near Idalia in the same county it passes through the intersection of the Idalia and English River faults. Further north it coincides with the Ironton fault in northeastern Iron County, passes through the Dent Branch cryptoexplosive structure in southern Washington County and terminates at the Leasburg fault in northeastern Crawford County.

The "Ironton lineament" is expressed as a series of faults and topographic escarpments in the igneous outcrop area and is continued northwestward on the basis of subsurface and aeromagnetic data. It is offset to the east by about 4.8 km north of its intersection with the east-west trending Palmer fault system in Washington County. Faults are observed in the sediments along portions of the lineament north of this intersection. The Shirley and Anthonies Mill faults, which roughly parallel the trace, lie only a few kilometers to the east. Drillhole data indicate a 60 to 100 meter displacement of the basement surface along the northern portion of the lineament, and a steep magnetic gradient, shown on aeromagnetic maps, is parallel to it. Several major Precambrian magnetic anomalies are localized along or near this lineament, including the Pilot Knob, Iron Mountain, Pea Ridge, Bourbon and Kratz Spring iron deposits. Pea Ridge in Washington County and Pilot Knob in Iron County are producing mines.

#11 NW South segment Strike N36°W; length 90 km. North segment Strike N34°W; length 300 km

The lineament begins at the Mississippi River near Point Pleasant in New Madrid County and extends a distance of nearly 400 km to near Madison in west-central Monroe County. The linear crosses the alluvial plain and Crowleys Ridge in the Embayment area and changes direction where it crosses the Ozark Escarpment (#3 NE) and intersects the "Ironton lineament" (#10 NW). In the St. Francois Mountains area it forms the southwestern boundary of the granite-felsite contact (granites to the northeast; felsites to the southwest). The trace crosses the Roselle lineament (#1 NS) just to the southeast of the town of Roselle and the junction of the Simms Mountain and Palmer fault systems in western St. Francois County. North of the "38th Parallel lineament", #5 EW (Palmer fault system), the trace coincides with the Aptus fault in central

Washington County. It crosses the Missouri River at Hermann and just north of the river it lies just to the west of the axis of the Mineola structure, roughly marking the western outcrop of Lower Ordovician and Devonian formations. The trace crosses the axis of the Mexico anticline in Audrain County at approximately right angles and terminates some 40 km northwest of Mexico in Monroe County. The lineament passes through the town of Potosi in the Southeast Missouri barite district which has minor lead and zinc mineralization. A linear array of barite-lead-zinc deposits closely follows the trend of the lineament along the Aptus fault zone in Washington County. This is one of the best examples of correlation between mineralization and major lineaments in the state. The lineament continues northward through both the North and South Fireclay districts. It lies along the northeastern flank of the Kratz Spring and Pea Ridge anomalies and extends across many anomalies in the southeast which represent Precambrian highs of the St. Francois Mountains. At the southernmost end it crosses essentially through the center of the Essex anomaly in Stoddard County.

#12 NW South segment ("West Belleview-East Sabula lineament")  
Strike N40°W; length 130 km. North segment Strike  
N42°W; length 315 km

The southern segment extends from Lodi in Wayne County to Interstate 70 between Bourbon and Cuba in Crawford County. The northern part extends from I-70 to the Missouri-Iowa state line in northwestern Mercer County.

The "West Belleview-East Sabula lineament" is 10 km to the southwest of the "Ironton lineament" and is parallel with it. It forms the southwestern boundary of the Belleview basin and the northeastern boundary of the Sabula basin, both down-dropped basement blocks in Iron County which terminate Precambrian outcrops. A large diabase dike is intruded along the "West Belleview" portion of the lineament. The lineament crosses the Taum Sauk caldera west of Ironton, where several parallel faults and diabase dikes were mapped (R. E. Anderson, 1970). In northern Wayne County the lineament terminates just south of a granite outcrop; at Lodi the granite has minor zinc mineralization. Southeast of Lodi, drillholes indicate a basement fault along the lineament. North of the Palmer fault system continuation of this lineament is indicated by parallel faults in the sediments (Berryman and Leasburg faults) and drillhole data indicate several hundred feet of displacement of the basement surface along its northwestern extension. The lineament is distinctly expressed on aeromagnetic maps.

In Crawford and Washington Counties, the "Ironton" and the "West Belleview-East Sabula" lineaments define a north-west-trending Precambrian high, composed of intermediate and

acid volcanics, that continues farther northwestward in the subsurface and is considered to be part of the northwestern extension of the Southeast Missouri Precambrian high (E. B. Kisvarsanyi, 1974).

The only structure on the northern portion of the trace is the Browns Station anticline in Boone County which lies about 2 km to the southwest of the trace. The mapped portion of the anticline has a length of about 25 km.

Mineralization along the trace is in the Palmer area (lead, zinc and barite) in southwestern Washington County and Precambrian copper mineralization is present at Ketcherside Gap in Iron County. The trace also passes through the North and South Fireclay districts and the Bevier coal field.

#13 NW ("Black River lineament") Strike N39°W; length 150 km

The lineament extends from just south of Greenville in central Wayne County to northwestern Crawford County. It marks the approximate southwestern boundary of the St. Francois Mountain block of Precambrian outcrops. A portion of it in northeastern Reynolds County coincides with the Black fault. Aeromagnetic maps indicate a discontinuous trend of isolated magnetic highs along the trace and magnetic lows where it marks the southwestern boundary of the Sabula Basin. The trace crosses the "38th Parallel lineament" (Palmer fault zone segment) with no apparent offset and terminates at the Cuba fault. The "Black River lineament" passes through the northern part of the Viburnum Trend, a major lead-zinc-copper mining district of Mississippi Valley type ore. There is also lead mineralization along the lineament in the vicinity of Annapolis in southern Iron County.

#14 NW ("Grand River lineament") South segment Strike N40°W; length 270 km. North segment Strike N44°W; length 280 km

One of the longer lineaments observed on the LANDSAT imagery extends from the "Bootheel" area of southeastern Butler County to northeastern Gentry County. Change in strike direction takes place where it crosses the Missouri River at Jefferson City, Cole County, in the central part of the state. The southern end of the segment begins about 50 kms south of the Ozarks Escarpment in the southeast embayment alluvial area. It crosses the Greenville fault and, where the trace crosses Clear Water Lake in southern Reynolds County, a dog-leg of the Black River drainage course coincides with the trace. To the north, it passes through the inner portion of a large circular feature between Bixby and West Fork (Iron and Reynolds Counties) and terminates in a larger outer semicircular feature lying to the southwest. The trace passes through the Crooked Creek cryptoexplosive structure in southwestern Crawford County and two structurally deformed areas of Pennsylvanian rocks -- the

Brunswick structure and the Bosworth structure -- in southwestern Chariton County. Two large segments of the Missouri River, between Jefferson City at the confluence of the Grand River with the Missouri at Brunswick in southern Chariton County, lie along the trace. The southern segment runs from Jefferson City to Rocheport, a distance of approximately 60 km; the northern segment runs from Glasgow in western Howard County to Brunswick, a distance of approximately 30 km. Along the segment from Rocheport to Brunswick, the trace nearly coincides with the axis of the Saline County arch.

The "Grand River lineament" passes between the Magmont and Buick mines (lead-zinc-copper-silver) and through the Boss magnetic anomaly (iron-copper mineralization) near the Dent-Iron County line. A number of magnetic anomalies, some quite large, lie along the northern segment from Rocheport to its terminus.

#15 NW ("Ellington fault lineament") South segment Strike N45°W;  
length 55 km  
Northern segment Strike N40°W; length 65 km

The trace extends from near Mill Spring in southwestern Wayne County to Lake Spring on the Dent-Phelps County line. From the southern end to Ellington, southern Reynolds County, the trace lies along drainage segments of the Black River and Doe Run Creek. The trace extends along the full extent (35 km) of the mapped segment of the Ellington fault and reconnaissance mapping indicates the fault may extend further north along the lineament. The lineament terminates at the Lake Spring magnetic anomaly. It marks the southern end of the southernmost lead mine in the Viburnum Trend, Ozark Lead Company Sweetwater mine, and forms the southern boundary of the north-south trending part of the Viburnum district.

#16 NW Strike N 40°W; length 60 km

The trace extends from Hunter in southeastern Carter County to eastern Shannon County. It is parallel to the northeastern boundary of the Eminence area of Precambrian knobs and coincides with several segments of the Current River. The lineament marks the southern boundary of a north-west-trending, buried basement high (probably a horst) in southern Reynolds County. There are no known mineral or magnetic features that show a relationship to the trace.

#17 NW South segment N48°W; length 100 km. North segment  
Strike N43°W; length 140 km

The trace extends from northeastern Ripley County to the Osage River at Bagnell in Miller County. The change in strike

direction takes place approximately 7 km south of Akers in northwestern Shannon County. The southern portion includes a number of segments of the Current River, the longest being a 10-km section near Van Buren. The trace passes through both Big Springs and Round Springs. The only mapped structure along the trace is the very short Sutton Creek fault in central Shannon County. The trace passes through the Eminence volcanics which appear on the imagery as a cluster of circles and semicircles. The trace terminates on a dog-leg of the Osage River which coincides with the trace.

#18 NW Strike N40°W; length 110 km

The trace begins just west of Montauk Springs in the southwestern corner of Dent County and terminates in Miller County at Bagnell on the Osage River. There are no mapped structures along the trace. The northern end of the segment lies along the northeastern flank of the Central barite district which includes some lead mineralization.

#19 NW Strike N47°W; length 35 km

The northern end of a very short linear in northeastern Camden County coincides approximately with the southern end of the Proctor anticline for a distance of 15 kms. The trace marks the southwestern boundary of the Lake Ozark portion of the Central barite district.

#20 NW Strike N39°W; length 190 km

The trace extends from the Arkansas line in southwestern Ripley County to Richland in Pulaski County. The trace continues into Arkansas. The middle portion, 85 km in length, marks the boundary between dolomites of the Jefferson City formation and sandstones and dolomites of the Roubidoux formation. The northern 75 km roughly marks the boundary of the western edge of the Steelville Brown Iron Ore district.

#21 NW Strike N47°W; length 290 km

The trace begins near Raymondville in central Texas County and extends to northeastern Jackson County. It passes through three circular structures, all observable on the LANDSAT imagery. They are a double circle in northwestern Texas County, a double circle coinciding with the Hazelgreen cryptoexplosive structure in east-central Laclede County and a double circle in southern Camden-northern Laclede County, coinciding with the Decaturville cryptoexplosive structure. It terminates at a double circle near Miller in northeastern

Jackson County which coincides with the "Lake City" magnetic anomaly but is in fact a topographic high. The lineament follows prominent and regionally persistent magnetic lineaments visible on aeromagnetic maps of central Missouri. It coincides with the "County-Line fault" (Laclede-Pulaski County boundary) and, to the northwest of the Decaturville structure, it approximately coincides with the Red Arrow fault. Portions of the trace coincide with stream drainage.

#22 NW Strike N45°W; length 40 km

Coinciding for most of its extent with Roubidoux Creek at the south and Missouri Highway 32 at the north, the linear extends from Bucyrus in central Texas County to Falcon in southeastern Laclede County. There is no apparent structural, geologic, magnetic or mineral association related to the trace and it is assumed that it reflects segments of Roubidoux Creek and Missouri Highway 32.

#23 NW Strike W50°W; length 300 km

The trace extends from central Oregon County between Alton and Greer Springs to Latour in southwestern Johnson County. The southern 100-km segment lies along the structural high mapped on the base of the Roubidoux formation from subsurface data. In Henry County, it lies approximately midway between the axis of the Lewis trough to the northeast and the LaDue-Freeman anticline to the southwest. These two structures, roughly parallel to one another, lie some 15 to 20 kms apart. Several short stream, road and railroad segments coincide with the trace; however, none are dominant enough or long enough to influence the entire length of the trace. There is no apparent relationship to features on the geologic map. The trace passes through the Tebo coal field in Henry County and the western edge of the Central barite district in Benton County. The only site of metallic mineralization along the trace is in northern Dallas County at the town of Lead Mine. To the northwest of Lead Mine, the trace parallels a straight northwest-southeast segment of the Little Niangua River. It is likely that the trace is reflecting a portion of this straight course and that it was misplaced when it was transferred from the image. The southern end of the trace lies some 10 km northeast of the Peace Valley magnetic anomaly and it passes along the northeastern flank of the Orla magnetic anomaly in southern Laclede County.

#29 NW South segment Strike N32°W; length 60 km. North segment Strike N23°W; length 55 km

The trace begins at the Missouri River in southern Buchanan County, crosses into a portion of Kansas, goes back



into Missouri in Holt County, and then goes to the Iowa line in northwestern Atchison County. The northern 40-km trace coincides with the Missouri River bluff line on the Missouri side and Interstate 29. The southern 75 km, on the Kansas side, represents a road and two straight valley segments.

#25 NW Strike N23°W; length 30 km

Located in western Atchison County, the trace represents a segment of the Chicago-Burlington and Quincy Railroad.

#26 NW ("Bolivar-Mansfield lineament") Strike N56°W;  
length 325 km

The trace begins at approximately the Arkansas line near the town of Thayer in southwestern Oregon County and extends northwesterly to near the Missouri-Kansas line in the vicinity of the town of Amoret in western Bates County. The southern 90 to 100 km show no structural features other than the small east-west trending Grand Gulf fault located near the southern terminus. The trace lines up with the Bolivar-Mansfield fault system in north-central Douglas County where it intersects the Mansfield fault. For the next 120 km, from approximately Denlow in central Douglas County to Fair Play in western Polk County, the trace coincides with a number of elements and segments of the fault system. From Fair Play northwestward to the state line, the trace becomes two nearly parallel segments. The northern one, striking N50°W, coincides with the axis of the Shell City-Rich Hill anticline as well as portions of the Eldorado Springs and Caplinger Mills faults. The northwestern segment of this lineament in Missouri coincides with a basement fault, believed to be the northeastern boundary of a graben (E. B. Kisvarsanyi, 1974).

The southern trace, a continuation of the main trace, extends to the state line and terminates near Worland in western Bates County. Portions of the southern trace coincide with the Eldorado Springs North fault and the Stockton fault. The southern portion of the trace also coincides with some stream segments and its central portion follows the Mississippian (on the southwest)-Lower Ordovician (on the northeast) boundary for a distance of 100 to 125 km. Mineralization includes some small abandoned mines and prospects in the Mansfield Cedar Gap area of southwestern Wright and northeastern Webster Counties. The linear passes through a minor northeast-southwest elongate, magnetic anomaly in northeastern Cedar County (Caplinger Mills).

#27 NW Strike N35°W; length 210 km

The linear begins in north-central Greene County and terminates in southwestern Jackson County. In Greene County,

the trace begins at a double circular LANDSAT feature near Ebenezer and terminates at a single circular feature in the southern part of Kansas City in western Jackson County. A short segment of the trace coincides with the Fair Play fault in Polk County. In the vicinity of the Humansville anticline, northwestern Polk County, there is a straight highway segment (Missouri Highway 13) which very likely is what the trace is reflecting. For the remainder of its distance, there are no structures; however, it does pass about 5 km southwest of the Weaubleau Creek structural complex. There are no known occurrences of metallic mineralization along the structure. At the north end, it passes through a broad, low magnetic anomaly in the vicinity of Belton, Cass County.

#28 NW Strike N45°W; length 80 km

A relatively short lineament begins at the Missouri-Arkansas line in southwestern Howell County and terminates north of Ava in north-central Douglas County. The central part of the trace coincides with the drainage of Bryant Creek for a distance of 30 km. The trace passes through the Caulfield Zinc district, an area of zinc-lead mineralization in southwestern Howell and southeastern Ozark Counties.

#29 NW Strike N12°W; length 160 km

The trace begins more than 160 km south of the Missouri-Arkansas line, enters Missouri in southeastern Taney County and terminates in the Strafford fault system in northeastern Greene County. There are no known structures along the trace in the Missouri portion. A number of zinc mines and prospects are present along the trace in the vicinity of Oldfield in eastern Christian County, and Rodgersville in southeastern Greene and southwestern Webster Counties. The trace passes along the eastern edge of the "Sparta" magnetic anomaly in the vicinity of Oldfield.

#30 NW ("Ten O'Clock Run-Chesapeake lineament") Strike N40°W; length 270 km

The lineament begins at the Missouri-Arkansas line in south-central Taney County and extends northwestward to the Missouri-Kansas line in Vernon County, continuing for another 70 kms into Kansas. The trace is in three segments and undoubtedly represents a fracture zone plus faulting. At its southern end, the trace parallels and in part coincides with the Ten O'Clock Run fault. In its central portion, it parallels the Chesapeake fault through Christian, Lawrence and Dade. Barton and Vernon Counties lie 2 to 7 km to the

northeast of the trace. The lineament also coincides and parallels the axis of the Golden City-Miller anticline in Lawrence and Barton Counties. The central segment of the linear lies on the northeastern edge of the Aurora-Stotts City zinc district. In central Barton County near Lamar, the lineament crosses a large, flat-topped, low-value magnetic anomaly.

### 3. North-South Trending Lineaments

Eight major lineaments, striking in a north-south direction, were observed on the LANDSAT imagery. In general, they are shorter than those striking in other directions -- east-west, northeast and northwest. The best known of the north-south lineaments observed is the Roselle (#1 NS), which has a length of 170 km. The longest is #3 NS, 350 km. The relationship of the north-south trending lineaments to the relief, general geologic setting, major structural features, magnetic anomalies and principal mineral resource areas in the state are shown on Figures IV-11 thru IV-15.

#1 NS ("Roselle lineament") Strike  $N7^{\circ}E$ ; length 170 km

The trace extends from northeastern Ripley County to the Mississippi River at Sulphur Springs in Jefferson County. The trace essentially coincides with a major north-south lineament having an approximate  $N5^{\circ}E$  trend identified by Gillerman (1968) on side-looking radar imagery and named the Roselle lineament. Along this lineament, near the St. Francois-Madison County boundary, three parallel faults in the igneous rocks were mapped by Amos and Desborough (1970). South of these faults, the Roselle lineament cuts across a strongly fractured block bounded on three sides by the Hogan (#10 NE), Ironton (#10 NW) and Annapolis (#8 NE) lineaments.

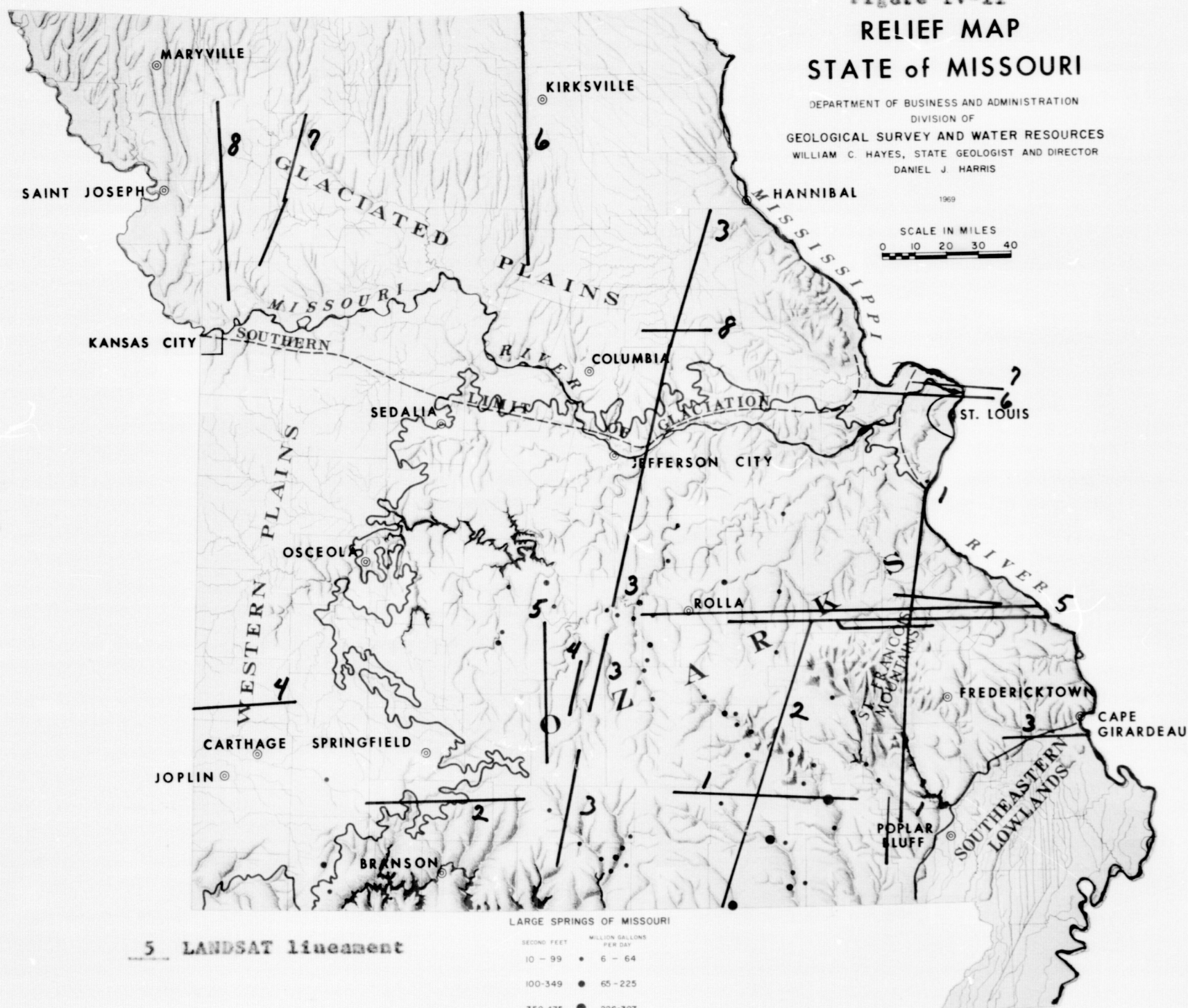
At the northern end of its trace, the "Roselle lineament" is nearly parallel to the Platin Creek anticline and crosses the Crystal City anticline. The final 10 to 15 km of the trace are aligned with a short segment of the Mississippi River before terminating at the Valmeyer anticline and fault. In its central portion, the lineament crosses the Vineland fault zone at the south end of the Ste. Genevieve fault system, the Farmington anticline and the Simms Mountain fault system. South of the main area of Precambrian outcrops, the Roselle crosses the Greenville fault in Wayne County, and terminates as a double lineament in the northeastern Ripley-northwestern Butler County area, some 25 km north of the Ozark Escarpment. Gillerman extended his radar lineament southward across the Escarpment into the Embayment region. The segment at the south end of the trace is approximately 25 km long and is offset 2 km to the west. It strikes parallel to the main trace. Portions

Figure IV-11  
RELIEF MAP  
STATE of MISSOURI

DEPARTMENT OF BUSINESS AND ADMINISTRATION  
DIVISION OF  
GEOLOGICAL SURVEY AND WATER RESOURCES  
WILLIAM C. HAYES, STATE GEOLOGIST AND DIRECTOR  
DANIEL J. HARRIS

1969

SCALE IN MILES  
0 10 20 30 40



27-35



Figure IV-12

# GEOLOGIC MAP OF MISSOURI

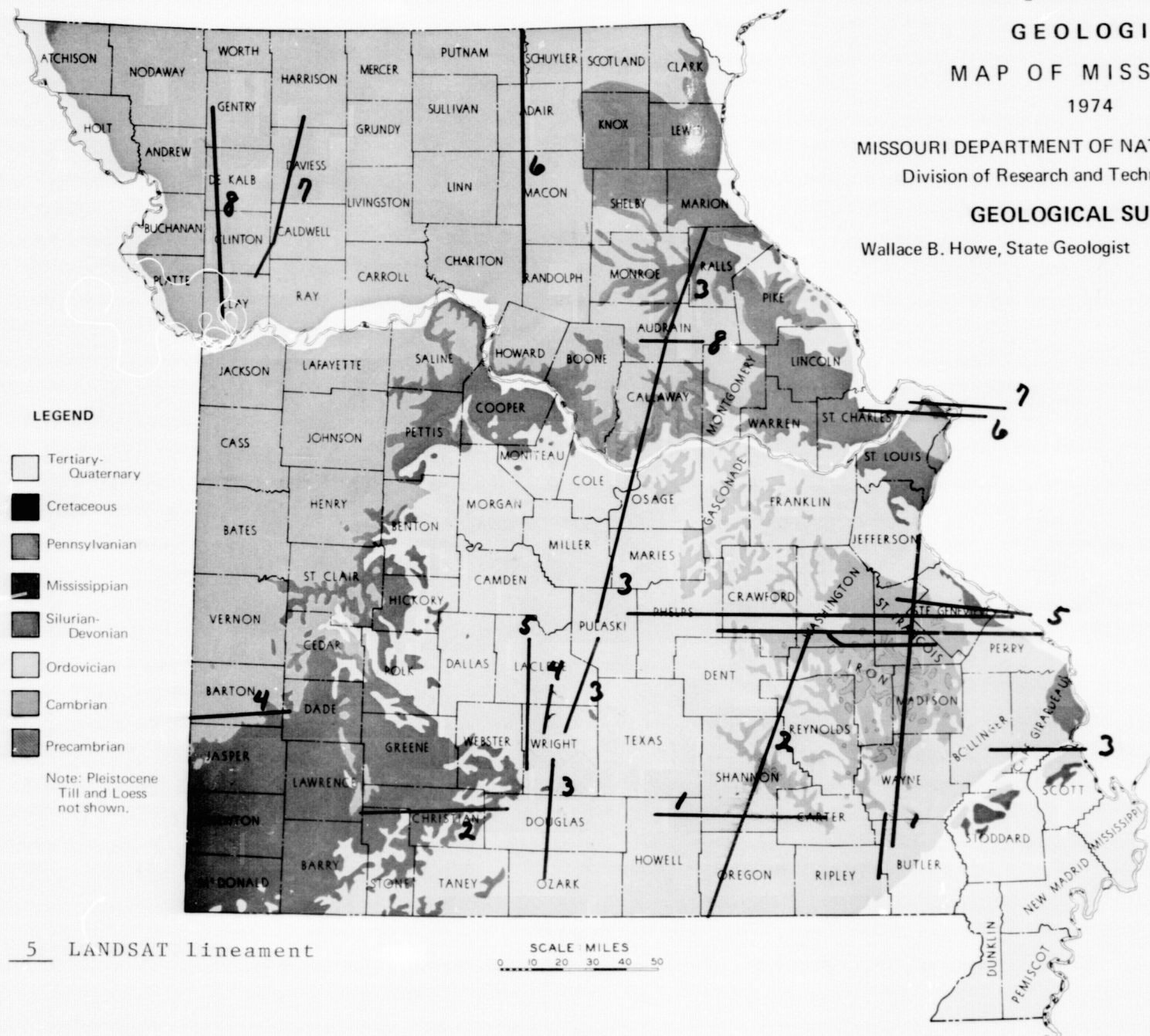
1974

MISSOURI DEPARTMENT OF NATURAL RESOURCES  
Division of Research and Technical Information

## GEOLOGICAL SURVEY

Wallace B. Howe, State Geologist

Rolla, Mo.



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Figure IV-13

GENERAL STRUCTURAL MAP  
SHOWING NS AND EW LINEAMENTS

MAJOR STRUCTURAL FEATURES  
OF MISSOURI

Mary H. McCracken  
1966

IV-37

- Contoured on base of the Roubidoux Formation
- - - Reconstructed in areas of complete removal of the Roubidoux by erosion

Contour interval 250 feet

- Approximate area of complete removal of the Roubidoux in the subsurface
- Area of pre-Roubidoux outcrop
- Fault  
Dashed where approximately located. U, upthrown side; D, downthrown side
- Anticline

5 LANDSAT lineament

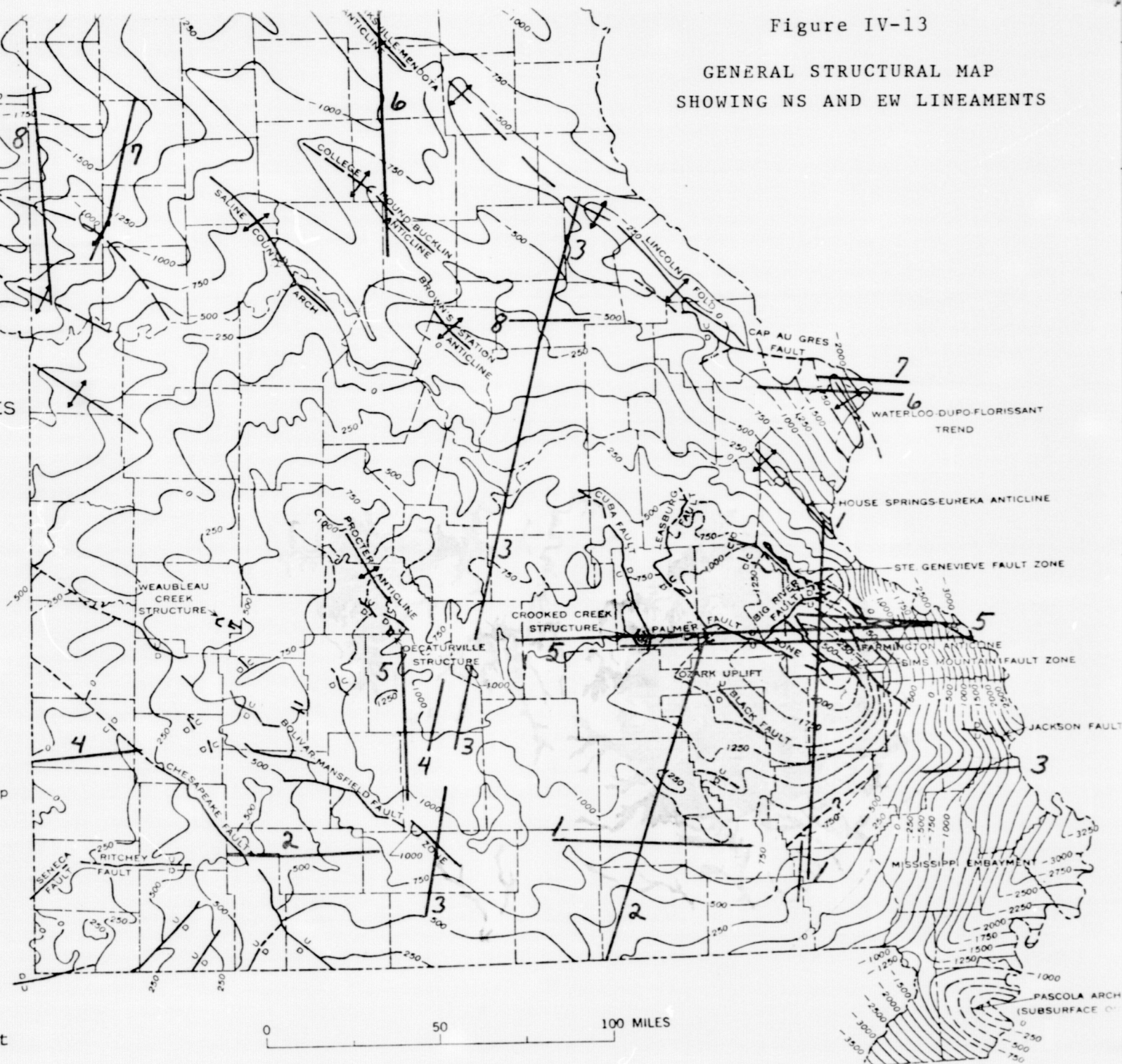
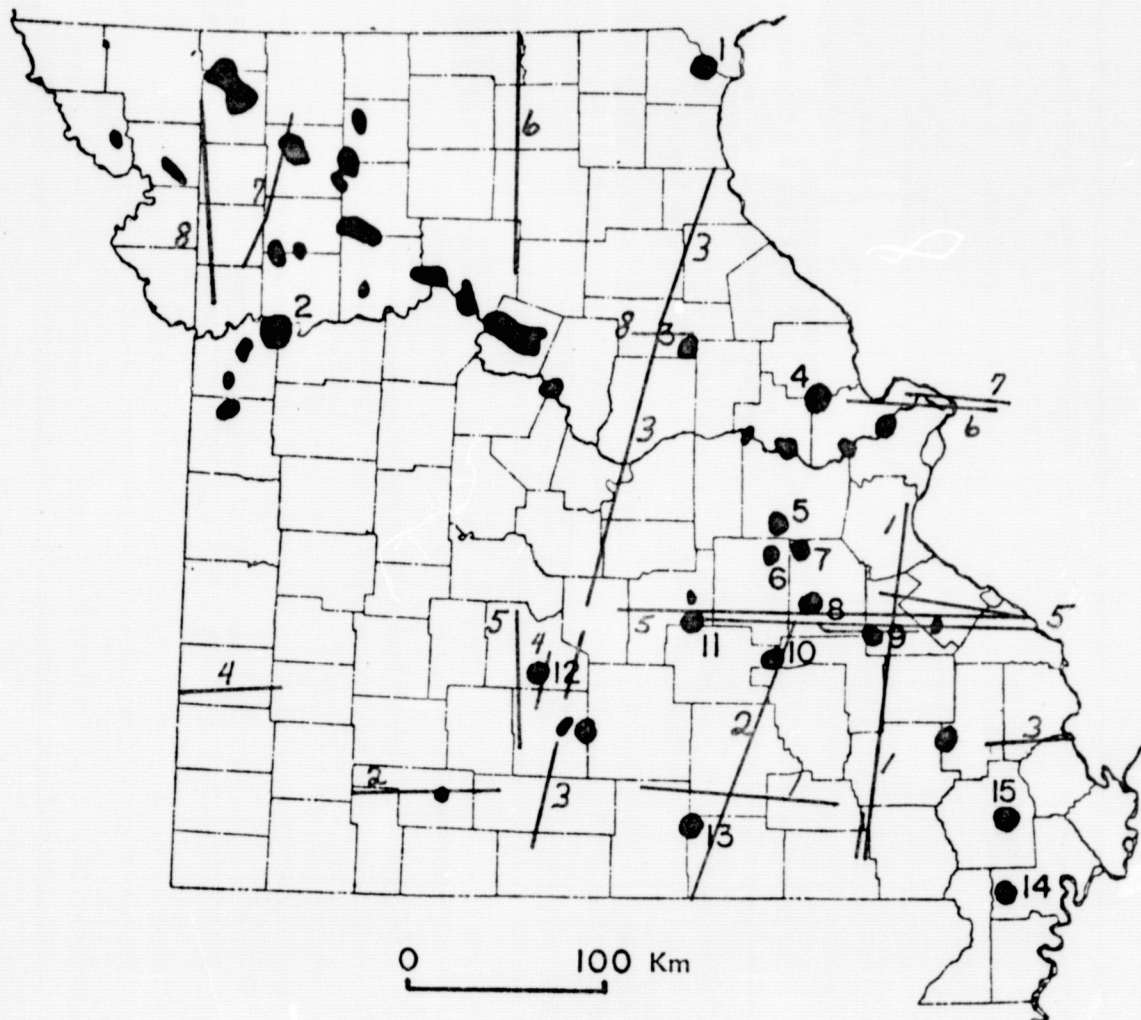




Figure IV-14

GENERAL MAGNETIC ANOMALY MAP  
SHOWING NS AND EW LINEAMENTS



- |                                      |                                       |
|--------------------------------------|---------------------------------------|
| 1 ST. FRANCISVILLE (mafic intrusive) | 9 IRON MOUNTAIN (iron mineralization) |
| 2 LEVASY (mafic intrusive)           | 10 BOSS (iron-copper mineralization)  |
| 3 BENTON CITY (mafic intrusive)      | 11 LAKE SPRING (iron mineralization)  |
| 4 WENTZVILLE (mafic intrusive)       | 12 ORLA (mafic intrusive)             |
| 5 KRATZ SPRING (iron mineralization) | 13 PEACE VALLEY (mafic intrusive)     |
| 6 BOURBON (iron mineralization)      | 14 MALDEN (unknown source)            |
| 7 PEA RIDGE (iron mineralization)    | 15 BLOOMFIELD (unknown source)        |
| 8 FLOYD TOWER (iron mineralization)  |                                       |

Figure IV-15

# MAJOR MINERAL COMMODITY AREAS OF MISSOURI

By W. C. Hayes and W. V. Searight

MISSOURI GEOLOGICAL SURVEY AND WATER RESOURCES  
William C. Hayes, State Geologist and Director  
Rolla, Mo.  
1969

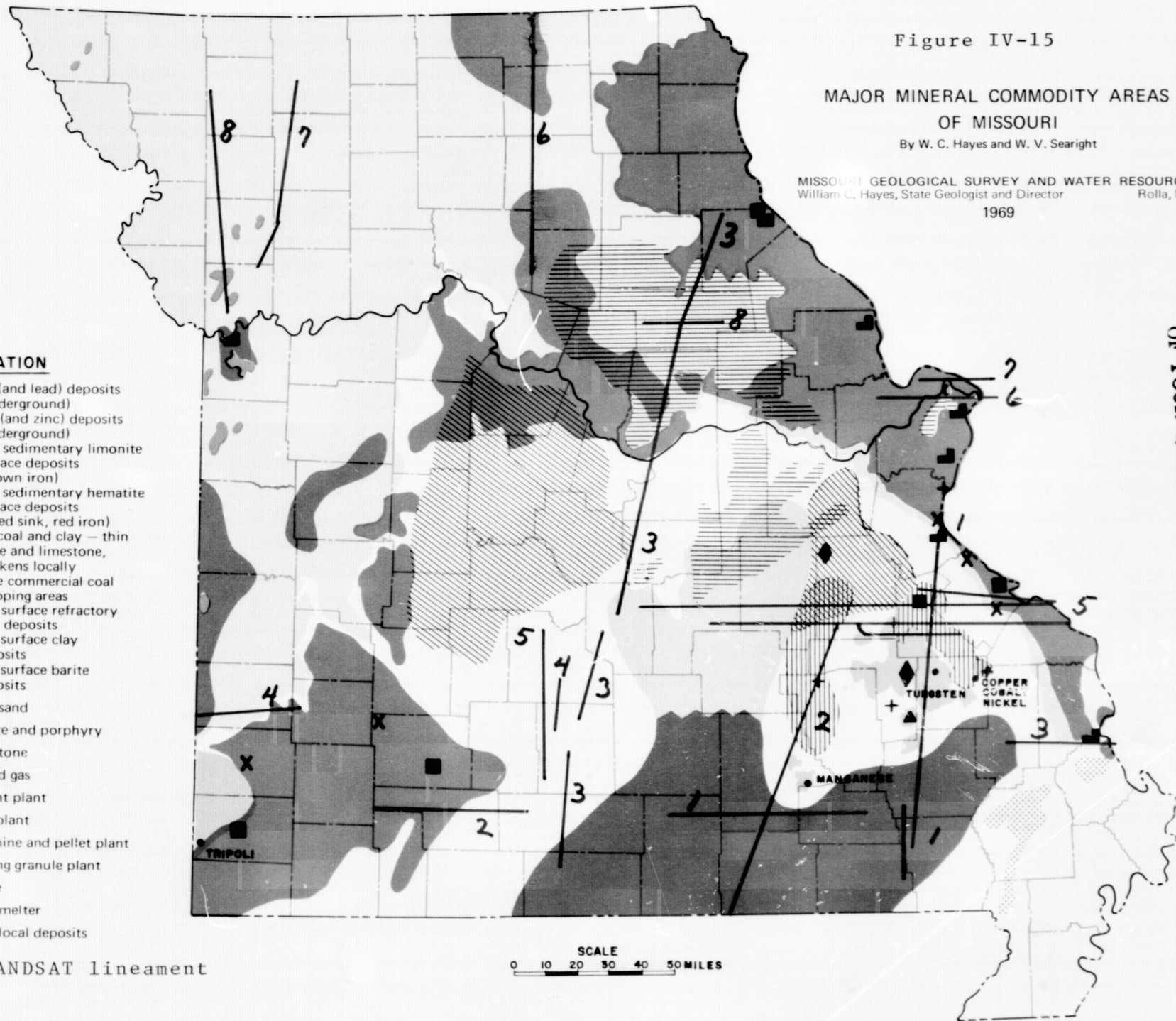
## EXPLANATION

- Zinc (and lead) deposits (underground)
- Lead (and zinc) deposits (underground)
- Local sedimentary limonite surface deposits (brown iron)
- Local sedimentary hematite surface deposits (filled sink, red iron)
- Thin coal and clay — thin shale and limestone, thickens locally
- Active commercial coal stripping areas
- Local surface refractory clay deposits
- Local surface clay deposits
- Local surface barite deposits
- Silica sand
- Granite and porphyry
- Limestone
- Oil and gas
- Cement plant
- Lime plant
- Iron mine and pellet plant
- Roofing granule plant
- Marble
- Lead smelter
- Other local deposits

5 LANDSAT lineament

SCALE  
0 10 20 30 40 50 MILES

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of the trace coincide with stream courses. In northeastern St. Francois County, it crosses a rather small but high magnetic anomaly and marks the eastern side of the Bonne Terre-Flat River portion of the Southeast Missouri Lead district.

#2 NS Strike  $N20^{\circ}E$ ; length 150 km

The lineament begins in northern Arkansas, 10 to 15 km south of the state line, enters the state in southwestern Oregon County, and terminates in the southwestern corner of Washington County at the southern trace of the double "38th Parallel lineament" (#5 EW). No folds or faults are known to coincide with the trace or are parallel with it at a close proximity. The lineament lies along the northwestern edge of the Ellington and Bee Fork circles in northeastern Shannon and western Reynolds Counties; it bisects a large semicircle seen on the imagery just northeast of Bunker and is tangential to the northwestern edge of the Oates circle in northwestern Iron and northern Reynolds Counties. The trace crosses both the Sutton Creek and Ellington faults without any apparent displacement. In Shannon County, it forms the northwestern edge of the Eminence outcrops of Precambrian volcanics. The northern termination of the trace is at the north end of the Viburnum Trend where it passes between St. Joe Minerals' Viburnum mines #27 and #28. The trace crosses the east flank of the Boss anomaly and passes between the Boss anomaly and the Magmont mine in western Iron County.

#3 NS Strike  $N13^{\circ}E$  to  $N18^{\circ}E$ ; length 350 km

The longest of the north-south lineaments, the trace consists of three discontinuous segments which begin in northwestern Ozark County and terminate at the Lincoln fold on the Ralls-Marion County line. Change in direction of strike takes place at the Callaway-Audrain County line near Auxvasse and only the northernmost 70 km have the  $N18^{\circ}E$  strike. The southern portion consists of two short segments separated by some 25 to 30 km. The southern one is 50 km long and the second is 45 km long. The third segment, which joins with the northernmost segment, is 135 km. There are no unusual geologic features or mineralization associated with the trace; however, it does lie some 5 to 10 km east of small zinc deposits in the Mansfield-Cedar Gap area of Wright County.

#4 NS Strike  $N10^{\circ}E$ ; length 45 km

A very short linear trace begins in north-central Wright County and extends into central Laclede County. The southern 20 km coincides with the Osage River and lies tangential to the east side of a double circle centered around the Hazelgreen cryptoexplosive structure. At its south end, the trace lies on the southeastern flank of the Orla magnetic anomaly.



#5 NS Strike North; length 75 km

The trace extends from southwestern Wright County to northern Laclede County. It passes through no major structures and there are no significant geologic changes along the trace. Portions of the trace coincide with a north-south segment of Missouri State Highway 5 and Park Creek, a tributary of the Gasconade River. The Orla magnetic anomaly lies between this linear and lineament #4 NS.

#6 NS ("Chariton River lineament") Strike North; length 135 km

The trace extends from the Randolph-Howard-Chariton County line, near Roanoke, to the Iowa line. The lineament represents the Chariton River drainage, a stream which has had much of its channel straightened. Interestingly, an extension of this linear southward for a distance of some 150 to 160 km would connect with lineament #5 NS.

#7 NS ("I-35 lineament") Strike N16°E; length 95 km

From its beginning at the town of Holt in northern Clay County to U. S. Highway 36 at Cameron in northwestern Caldwell County, the trace coincides with Interstate Highway 35. From U. S. 36 to State Highway 6 in Daviess County, the Interstate lies immediately to the west of the trace and, from Highway 6 to its termination near Bethany in central Harrison County, the trace again coincides with I-35. The trace is considered a reflection of the Interstate Highway.

#8 NS Strike N5°W; length 110 km

The lineament extends from southern Clay County northward to near Stanberry in Gentry County. Lying at the south end of the trace is the Shoal Creek structure, one of several anomalous areas of steeply dipping, downwarped Pennsylvanian rocks present in northern Missouri. There are no other structures that coincide with or parallel the trace in close proximity. A circular feature observed on the imagery in southwestern Clinton County is on the trace. Short highway segments, stream drainage and a portion of an electric transmission line lie along the trace. The northern end of the trace is immediately west of the large magnetic anomaly in central Gentry County.

#### 4. East-West Trending Lineaments

Eight essentially east-west lineaments were noted on the imagery. As with the other traces, the majority are located in the southeastern part of the state. The longest of the east-west trending lineaments is the 200 km double trace (#5 EW) lying along the projection of the "38th Parallel lineament" (Snyder and Gerdemann, 1965; Heyl, 1972), a proposed east-west fracture pattern of continental proportions. Figures IV-11 thru IV-15 show the relationship of the east-west lineaments with the relief, general geologic setting, major structural features, magnetic anomalies and principal mineral resource areas in the state.

#1 EW Strike  $N86^{\circ}W$ ; length 75 km

The trace extends from Mountain View in northeastern Howell County to near Ellsinore in northeastern Carter County. Portions of the trace coincide with or are immediately adjacent to segments of U. S. Highway 60 and the St. Louis-San Francisco Railroad and the course of the channel of Pike Creek. It terminates 15 km. east of Van Buren in central Carter County. The segment from Van Buren eastward is the one part of the trace which does not coincide with culture or drainage.

#2 EW Strike  $N88^{\circ}E$ ; length 60 km

The trace extends from Brown Spring in northwestern Stone County to near Dogwood in northwestern Douglas County. The eastern half of the trace that extends from Dogwood to Ozark in central Christian County, coincides with Missouri State Highway 14. The western half, from Ozark to Brown Spring, has no apparent cultural connection but does follow a short stream course in the eastern third. The trace intersects with northwest-trending lineament #29 near Oldfield and passes through areas of known lead mineralization and small deposits near Ozark and Bruner in Christian County.

#3 EW Strike E-W; length 40 km

The lineament is in eastern Bollinger, southern Cape Girardeau and northern Scott Counties in Southeast Missouri. Portions of the trace coincide with a major diversion channel in the Embayment region as well as with a segment of the St. Louis-San Francisco Railroad. There is no apparent connection with structure, bedrock geology, magnetics or mineralization.

#4 EW Strike  $N3^{\circ}E$ ; length 40 km

The trace extends from the Missouri-Kansas line in southwestern Barton County eastward to the Barton-Dade County line.

It extends some 80 km in a westward direction into Kansas. Several synclinal and anticlinal trends are crossed, but there are no structures coinciding with or immediately adjacent to the trace. It is tangential to the largest circle ("Vernon-Cedar-Barton County circle") observed on the LANDSAT imagery. There is no readily apparent relationship to the geology, structure or magnetics or to areas of known mineralization. The trace does mark approximately the southern limit of the Southwest coal field in Barton County.

#5 EW ("38th Parallel lineament"; Palmer-Ste Genevieve fault system lineament; "Rueff lineament") Strike E-W; length North trace 200 km, South trace 150 km

A double trace enters Missouri from Illinois in the vicinity of McBride and Menfro in northeastern Perry County. The northern trace extends westward to Devils Elbow near the Phelps-Pulaski County line; the southern trace terminates at the Phelps-Crawford County line near Cooks Station in southwestern Crawford County. The traces are parallel and approximately 5 km apart.

The lineament is identified by major Paleozoic fault systems that probably involved the basement rocks as well. The northern trace coincides with the Ste. Genevieve fault system from McBride which is also the point at which the fault system changes strike from northeast to essentially east-west then westward for 30 km to where the fault zone again changes strike to a northwestern direction. From south-central Washington County to southwestern Crawford County, the trace coincides with the Palmer fault system for a distance of 40 km to where the fault system terminates in the Crooked Creek cryptoexplosive structure. The trace continues eastward into Illinois. It has been suggested (Heyl, 1972) that the 38th Parallel lineament connects the Ste. Genevieve fault system with the Cottage Grove-Rough Creek fault system of southern Illinois. The lineament crosses the Farmington anticline and the northwest-trending Simms Mountain fault system at its junction with the northeast-trending Big River fault system without any apparent break or offset of the trace.

Snyder and Gerdemann (1965) have suggested that the 38th Parallel lineament marks a zone of crustal weakness along which intermittent deep-seated faulting, accompanied by igneous intrusions and explosive volcanism, occurred through a long period of time. The Avon diatremes and intrusive dikes in southern Ste. Genevieve County (Kidwell, 1947), the Furnace Creek (Snyder and Gerdemann, 1965) and Dent Branch structures (Wagner and E. B. Kisvarsanyi, 1969) in southern Washington County, and the Crooked Creek cryptoexplosion structure in southwestern Crawford County are such examples along the 38th Parallel zone in Southeast Missouri. East-West lineaments,

such as the 38th Parallel lineament, may have controlled the emplacement of iron-ore deposits and basic dikes, especially where they cross major NW-trending the NE-trending lineaments (G. Kisvarsanyi, 1966).

The southern trace of the 38th Parallel lineament forms the southern boundary of the Bonne Terre-Flat River-Elvins Old Lead Belt district and, in western Iron County, it marks the northern end of the Viburnum Trend. The northern trace passes through the center of the Bonne Terre-Flat River-Elvins Old Lead Belt district and lies immediately south of the Palmer area of barite-lead mineralization. A third trace lies 2 km south of the double trace and parallels it for a distance of 50 km, extending from the Avon diatreme area of southwestern Ste. Genevieve County to the Dent Branch structure near Caledonia in south-central Washington County. At the Dent Branch structure, the trace swings northwestward and joins the southern trace.

#6 EW Strike  $N86^{\circ}W$ ; length 65 km

The trace begins at the junction of the Mississippi and Missouri Rivers in northern St. Louis County and extends to near the vicinity of Flint Hill in northwestern St. Charles County. It continues eastward into Illinois. An east-west segment of the Missouri River just downstream (northeast) of St. Charles parallels the trace. The termination of the linear is near the western edge of a broad magnetic anomaly in northwestern St. Charles County. The trace passes through the Florissant oil pool in northern St. Louis County and, in part, roughly approximates the Pennsylvanian-Mississippian boundary in the same area.

#7 EW Strike  $N80^{\circ}W$ ; length 35 km

A short linear, lying 3 to 5 km north of #6 NE, extends from Illinois into the extreme eastern part of St. Charles County, terminating near Orchard Farm. The trace is at the northern end of the Florissant dome.

#8 EW Strike  $N88^{\circ}W$ ; length 35 km

The trace is in southern Audrain County and extends from Missouri Highway 19, westward to Davis Creek, about 10 km west of Mexico. It passes through Mexico, crosses the Mexico anticline and terminates just to the east of the mapped axis of the Davis Creek anticline. The easternmost 20 km coincide with U. S. Highway 54 and the western 10 km coincide with portions of Davis Creek.



## 5. Circular and Arcuate Traces

More than 40 single and double circular lineaments were observed on the imagery. Some circular features are completely enclosed. Others are represented only by segments. Sub-circular and elliptical shapes are common. Some appear to be cut off by others as though implying an age relationship. Some are clustered on volcanic terranes but others are present where the Precambrian basement is more than 450 meters deep. Common diameter of these features is approximately 10 km. The largest one, centered on the village of Montevello in Vernon County in southwestern Missouri, has a diameter of 70 km. Several groups of circular lineaments are aligned to the northeast and northwest. The circular and arcuate features are concentrated in four regions of the state: northwest, southwest, south-central and southeast. The largest concentration is in the Southeast which is further subdivided into five groups for discussion.

Figures IV-16 thru IV-20 show the distribution of circular traces and their relationship to relief, general geologic setting, major structural features, magnetic anomalies and principal mineral resource areas in the state.

Northwest Missouri: A total of ten circles and two arcs were observed on the imagery of this area. Three of the circles are in the Kansas City area, one is in southern Harrison County and the remainder are in the northwestern corner. Both arcs are in the northwestern corner of the state.

In the Kansas City area, the smallest circle (6 km in diameter) is located near the town of Trimble in southwestern Clinton County. There are oil pools lying to the northeast and southeast of the circle which is bisected by lineament #8 NS. There is no apparent direct relationship to the geologic setting, magnetics or structure of the area. The second circle lies in the southwestern part of Kansas City in western Jackson County and is bisected by the Missouri-Kansas state line. The circle is approximately 10 km in diameter. It lies at the northern end of lineament #27 NW. The third circle in the Kansas City area is in north-central Jackson County, just to the west of the town of Levasy. It is a double circle with the inner trace having a diameter of 9 km and the outer, 15 km. The inner circle outlines a topographic high which is bounded on the west by the Little Blue River, on the north by the Missouri River floodplain and on the south and east by an abandoned channel of the Little Blue River which is now occupied by the Missouri Pacific Railroad. The outer circle reflects the western side of the Little Blue Valley and the southeastern side of the abandoned channel. The eastern trace of the outer circle coalesces with the inner circle and they share a common trace.

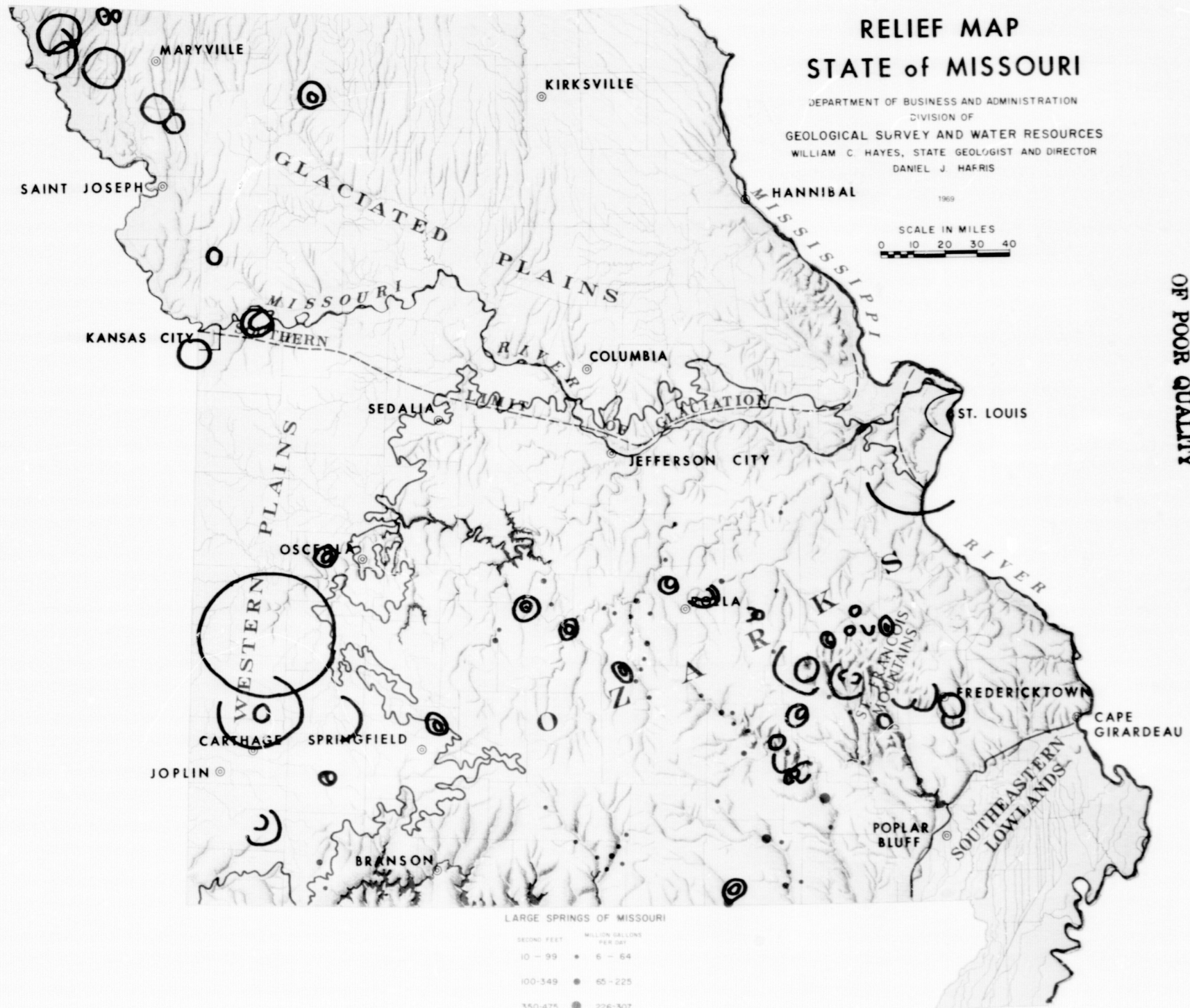
Figure IV-16

# RELIEF MAP STATE of MISSOURI

DEPARTMENT OF BUSINESS AND ADMINISTRATION  
DIVISION OF  
GEOLOGICAL SURVEY AND WATER RESOURCES  
WILLIAM C. HAYES, STATE GEOLOGIST AND DIRECTOR  
DANIEL J. HAFRIS

1969

SCALE IN MILES  
0 10 20 30 40



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Figure IV-17

GEOLOGIC

MAP OF MISSOURI

1974

MISSOURI DEPARTMENT OF NATURAL RESOURCES

Division of Research and Technical Information

GEOLOGICAL SURVEY

Wallace B. Howe, State Geologist

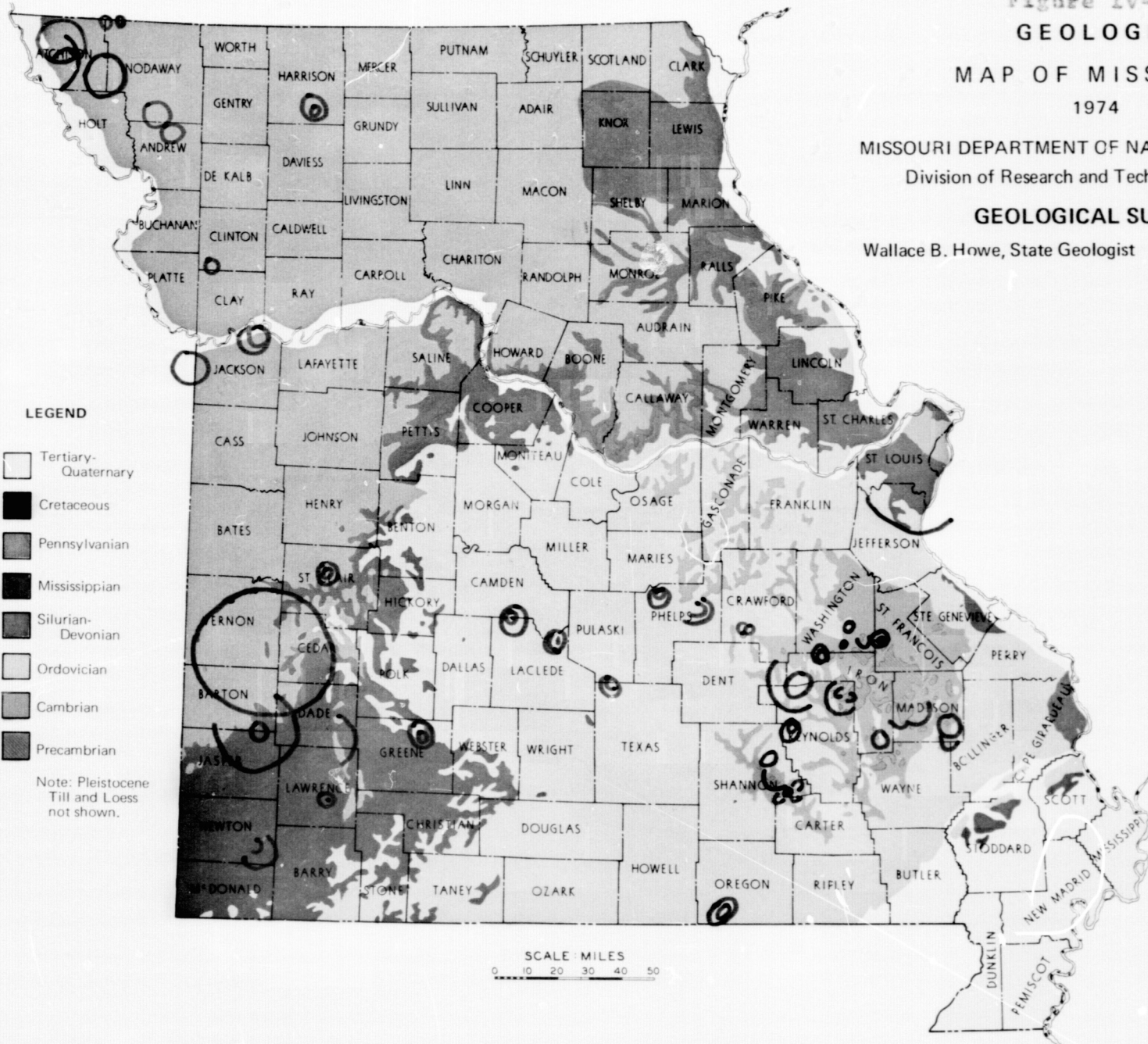
Rolla, Mo.

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LEGEND

-  Tertiary-Quaternary
-  Cretaceous
-  Pennsylvanian
-  Mississippian
-  Silurian-Devonian
-  Ordovician
-  Cambrian
-  Precambrian

Note: Pleistocene  
Till and Loess  
not shown.



SCALE MILES

0 10 20 30 40 50



Figure IV-18

GENERAL STRUCTURAL MAP  
SHOWING CIRCULAR FEATURES

MAJOR STRUCTURAL FEATURES  
OF MISSOURI

Mary H. McCracken  
1966

IV-48

Contoured on base of the  
Roubidoux Formation

Reconstructed in areas of  
complete removal of the  
Roubidoux by erosion

Contour interval 250 feet

Approximate area of complete  
removal of the Roubidoux in  
the subsurface

Area of pre-Roubidoux outcrop

Fault  
Dashed where approximately  
located. U, upthrown side;  
D, downthrown side

Anticline

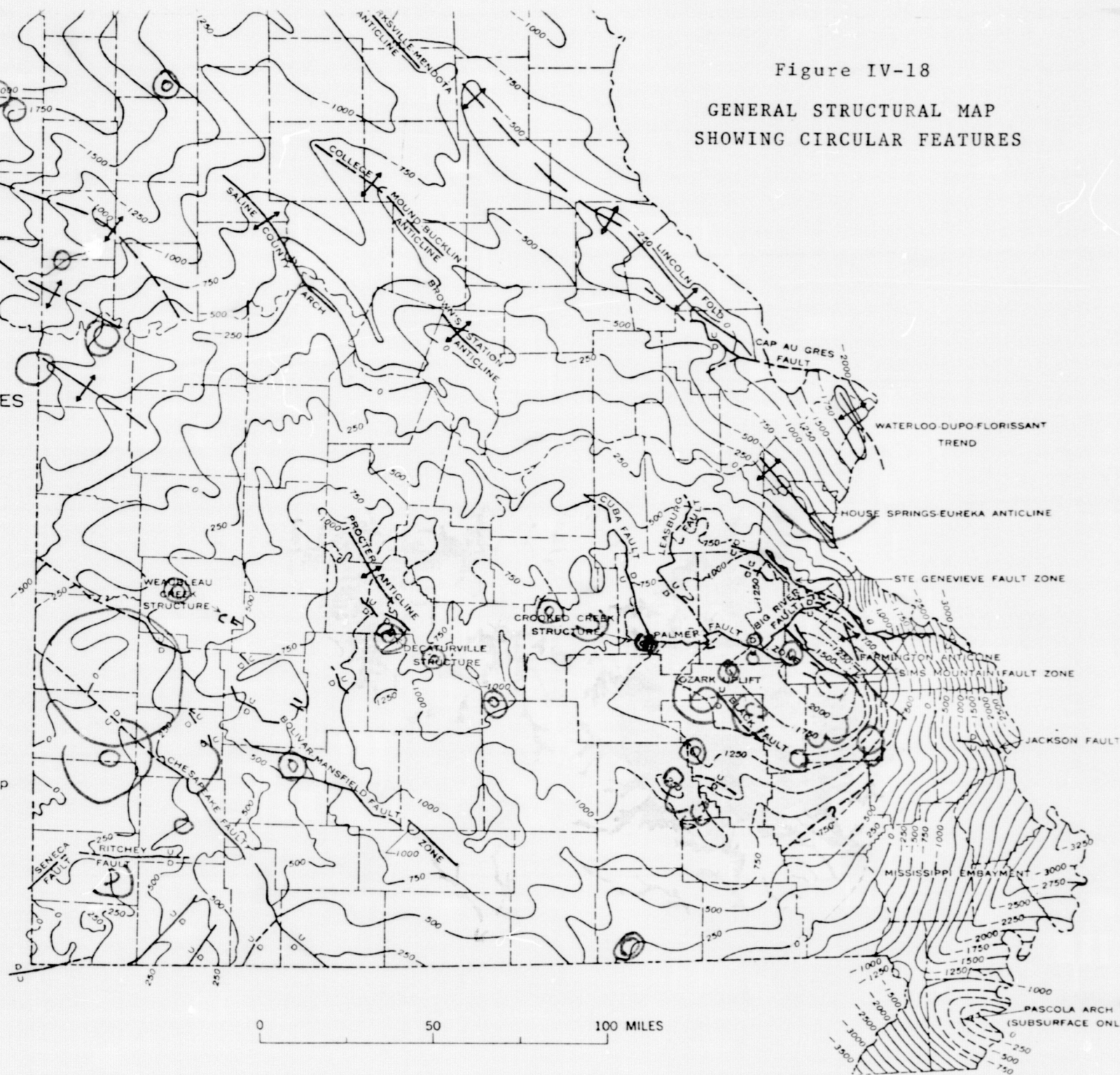
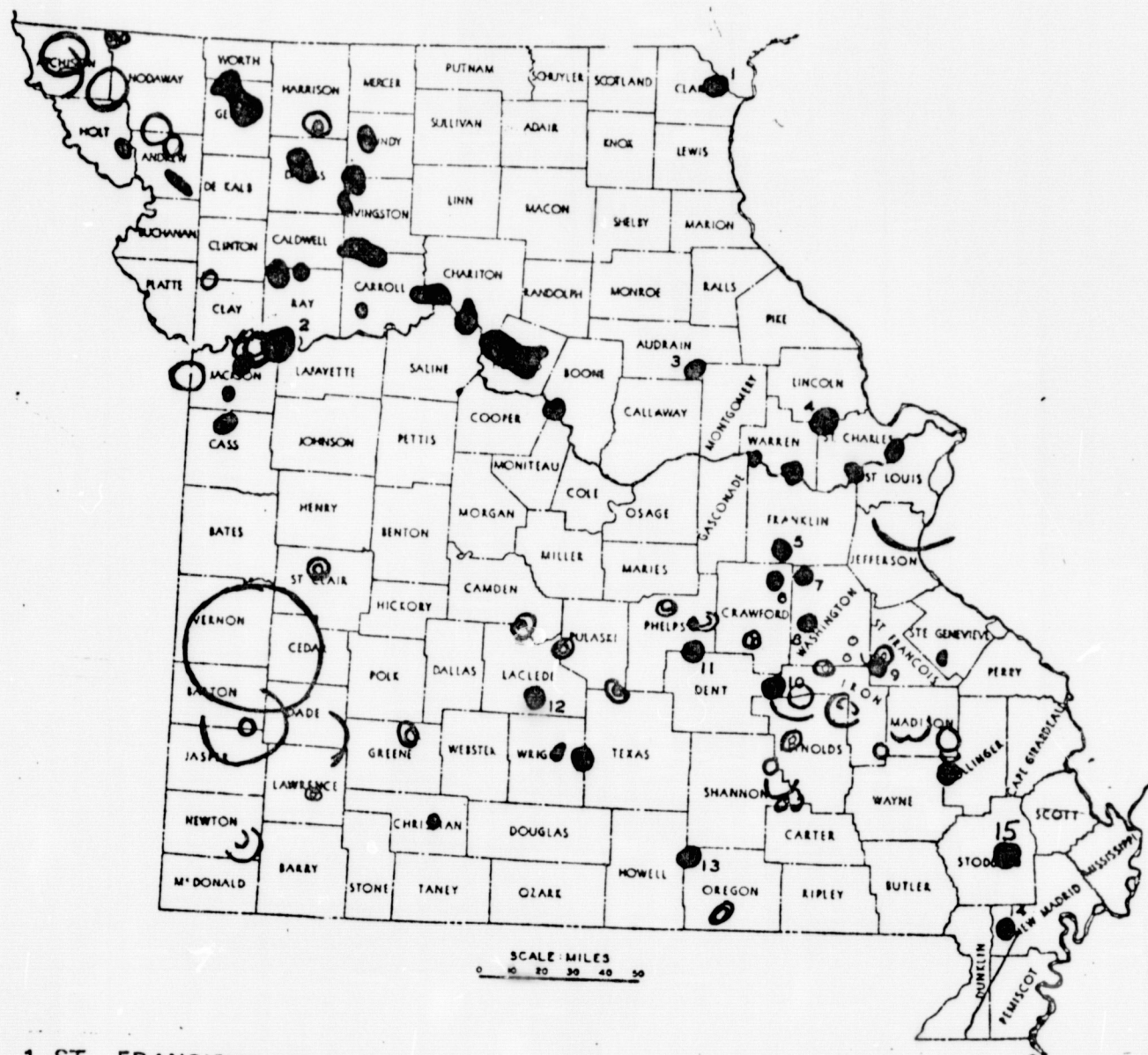


Figure IV-19

GENERAL MAGNETIC ANOMALY MAP  
SHOWING CIRCULAR FEATURES



- |                                      |                                       |
|--------------------------------------|---------------------------------------|
| 1 ST. FRANCISVILLE (mafic intrusive) | 9 IRON MOUNTAIN (iron mineralization) |
| 2 LEVASY (mafic intrusive)           | 10 BOSS (iron-copper mineralization)  |
| 3 BENTON CITY (mafic intrusive)      | 11 LAKE SPRING (iron mineralization)  |
| 4 WENTZVILLE (mafic intrusive)       | 12 ORLA (mafic intrusive)             |
| 5 KRATZ SPRING (iron mineralization) | 13 PEACE VALLEY (mafic intrusive)     |
| 6 BOURBON (iron mineralization)      | 14 MALDEN (unknown source)            |
| 7 PEA RIDGE (iron mineralization)    | 15 BLOOMFIELD (unknown source)        |
| 8 FLOYD TOWER (iron mineralization)  |                                       |

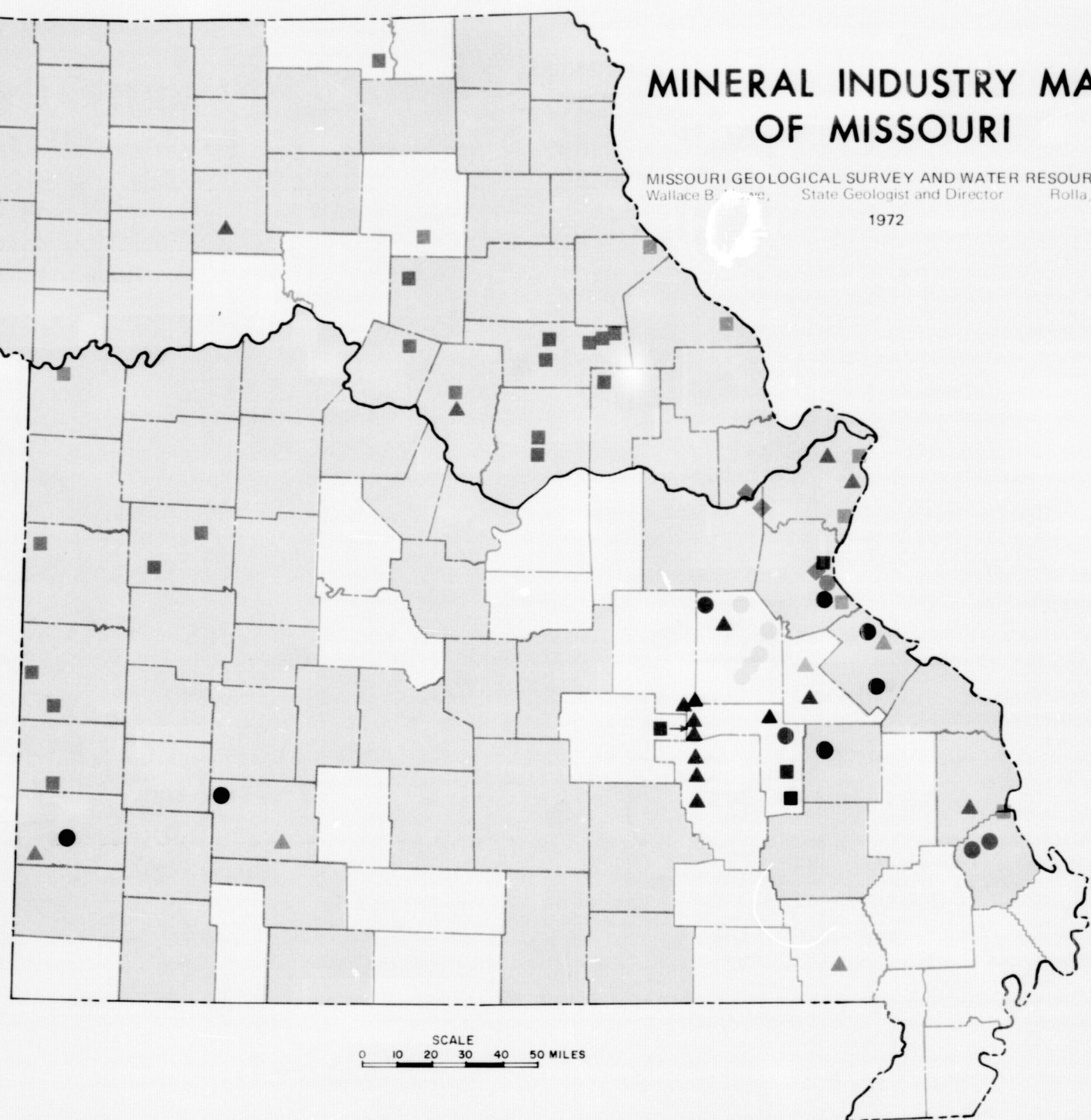


# MINERAL INDUSTRY MAP OF MISSOURI

MISSOURI GEOLOGICAL SURVEY AND WATER RESOURCES  
Wallace B. Galloway, State Geologist and Director Rolla, Mo.  
1972

## EXPLANATION

- Barite; Mines, Mills, Washers & Grinding Plants
- Cement Plants
- Clay Products
- Absorbent Clay
- ▲ Brick & Tile
- ◆ Lightweight Aggregate
- Refractories
- Coal Mines
- Iron Mines & Pellet Plants
- ▲ Lead Mine & Mill
- Lead Smelter
- ▲ Lime Plant
- Plate Glass Plant
- Marble & Terrazzo
- ▲ Dimension Granite
- Roofing Granules
- ▲ Tripoli
- ◆ Silica Sand Quarries
- Counties with Limestone & Dolomite Quarries



SCALE  
0 10 20 30 40 50 MILES

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Figure IV-20

# MINERAL RESOURCE MAP OF MISSOURI

MISSOURI GEOLOGICAL SURVEY AND WATER RESOURCES  
Wallace B. Howe, State Geologist & Director Rolla, Mo.

1972

## METALS

Iron

- Magnetite
- ▨ Sedimentary (limonite & hematite)

Lead & Zinc

- ▨ Lead with Zinc, Copper, and Silver
- ▨ Zinc with Lead

Misc. Deposits

- × Copper
- ⊠ Copper Cobalt Nickel
- ▲ Copper-Iron
- ⊕ Manganese
- △ Tungsten

## NONMETALS

- ▨ Barite — Major District
- ▨ Barite with Lead — Minor District

Clay

- ▨ Clay & Shale
- ▨ Absorbent Clay
- ▨ Refractory Clay

Silica Sand

Sand & Gravel\*

Stone

- ▨ Thin Limestones
- ▨ High-Calcium Limestone
- ▨ High-Magnesium Dolomite
- ▨ Granite & Felsite
- ▨ Tripoli

## MINERAL FUELS

- ▨ Area underlain by coal bearing strata
- ▨ Major Coal Districts
- ▨ Oil & Gas Fields
- ▨ Heavy Oil (undeveloped)

SCALE  
0 10 20 30 40 50 MILES

\*Sand and gravel—along major stream channels. Not shown on the map.

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IV-50



Lineament #21 NW terminates at the circle. Although it can be demonstrated that the double circle reflects topography, drainage and a cultural feature, it is noted that the circle lies just to the southwest of a major magnetic anomaly known as the Levasy anomaly caused by a mafic intrusive, and overlies a smaller satellite anomaly (Lake City). Of all the circles seen on the LANDSAT imagery, this is the only one that comes close to coinciding with a major buried magnetic anomaly.

A lone double-ring circle, having a diameter of 13 km for the outer ring and 5 km for the inner, is located in south-central Harrison County. The Trenton anticline passes through the northeastern corner of the circle and the circle itself is bounded on the north by lineament #3 NW and on the southwest by lineament #14 NW. The center of the circle is about 5 km southeast of the Bethany structure, which lies on the outer circle. The Bethany structure is one of several occurrences of steeply dipping, downwarped Pennsylvanian rock found well below their normal stratigraphic position. The double circle lies in a magnetically low area with high anomalies to the west, east and south.

The largest number in this region, six circles and two arcs, are in the northwestern corner of the state in Andrew, Nodaway, Holt and Atchison Counties. Four circles and two arcs are aligned in a northwest-southeast direction with an axis strike of approximately N55°W. This is on line with the Cameron-Union Star syncline whose mapped extent terminates 15 km to the southeast. The four circles are located in north-central Andrew County and extend into the northwestern corner of Atchison County. They show an increase in size to the northwest with the smallest circle (10 km in diameter) at the southeastern end and the largest (20 km in diameter) at the northwestern end. The intervening circles, from southeast to northwest, are 17 and 13 km in diameter, respectively. In addition to lying along the strike of an extension of the Cameron-Union Star syncline, the northeastern flank of the series of four circles is adjacent to and roughly parallel with the axis of the Hamilton-King City-Quitman anticline. Comparing the alignment of the four circles with subsurface data, their axis lies essentially along the northwest-plunging axis of a syncline mapped on the base of the Roubidoux Formation which lies some 600 to 900 meters below the surface of the area. The Tarkio Pool, a small oil field on the southeastern flank of the Forest City basin, lies between the two northwesternmost circles in Atchison County. The four circles are in a magnetically low area between the Gentry County anomaly to the northeast and the Holt-Andrew County anomaly to the southwest. Two small circles are located in the northeastern corner of Atchison County and the northwestern corner of Nodaway County.

Each has a diameter of approximately 5 km and could be considered satellite circles to the northwest-trending line of four. The circles are on a line that strikes N35°E and connects the Corning and Tarkio structures (both of which are small oil pools) in Atchison County.

Southwest Missouri: Five circles -- two of which are double or "bulls eyes" -- and four arcs were observed. The largest circular feature observed on the LANDSAT imagery, 70 km in diameter, lies in this area in Vernon, Cedar, Barton and Dade Counties with its approximate center at Montevallo in southeastern Vernon County. The circle, which roughly defines a magnetic low, is a roughly rectangular-shaped feature rather than a circular one and is informally referred to as the "Nevada basin", after the principal town in the area. Portions of the trace reflect drainage patterns in the west, south and east. The circle is bisected by lineament #26 NW ("Eldorado Springs lineament") which is a double linear roughly coinciding with the folding and faulting of the Bolivar-Mansfield fault system. It passes through the northeastern part of the circle and roughly marks the linear magnetic high bounding the northwestern flank of the "Nevada basin". Immediately to the south of the large circle is a 40-km, three-quarter arc having a small 7 km-diameter circle at its center. Large portions of the outer arc coincide with stream drainage in the area. There is no indication as to what the inner circle reflects.

Approximately 45 to 50 km to the south in the southeastern corner of Newton County, two arcs (approximately three-quarters of a circle each) have major portions coinciding with drainage. Diameters are 15 km for the outer arc and 7 km for the inner arc. These traces lie at the southwestern end of a series of four double or "bulls eye" circles that lie along a 240-km segment of lineament #23 NE, extending from near Fairview in southeastern Newton County to the northwestern corner of Phelps County. Two of the circles are located in the Southwest region and two are in the South-central. The two in the Southwest region are located in south-central Lawrence County near Mount Vernon and northeastern Greene County near Ebenezer. The Lawrence County circle is the smallest having an elliptical shape with an outer diameter of 3 to 7 km and an inner diameter of 2 km. Segments of both circles coincide with drainage. The Greene County circle, also elliptical in shape has an outer diameter of from 8 to 12 km and an inner diameter of 5 km. The circle is 55 km northeast of the Lawrence County circle and is located in the Bolivar-Mansfield fault system, a zone of faulting and folding. Portions of both outer and inner circles coincide with drainage; however, this does not seem to be the dominant element and a detailed field examination seems warranted.

A semicircle in southeastern Dade County is in an area of faulting and folding immediately south of the Bolivar-Mansfield fault system; however, much of the trace coincides with drainage and it is felt the entire feature reflects segments of stream drainage in the area.

The final circular feature in the Southwest region is a double circle in north-central St. Clair County, west of Lowery City. The outer circle has a diameter of 12 km and the inner, a diameter of 7 km. The circle lies about midway along lineament #27 NW, which has the Green County circle at its southeastern end, and the southern Kansas City circle at its northwestern end. Small segments of the outer circle lie on or near drainage. Overall the circles do not appear to be drainage controlled; however, neither is there an apparent relationship to structure, geologic boundaries or magnetic anomalies.

South-central Missouri: Five circles, four of which are double circles and one, double semicircle were observed. Two of the circles, one in east-central Laclede County and the other in northwestern Phelps County, lie along lineament #23 NE. Three of the circles in southeastern Camden County, east-central Laclede and southwestern Crawford County, outline the Decaturville, Hazelgreen and Crooked Creek cryptoexplosive structures, respectively. Both Crooked Creek and Decaturville have outcrop expressions; the Hazelgreen structure is known principally from deep drilling. The Decaturville, Hazelgreen and an unnamed double circle in northwestern Texas County lie along a 70-km segment of lineament #21 NW. In addition to those circles lying on major northeast- and northwest-trending lineaments, the Crooked Creek structure is on lineament #5 EW (38th Parallel lineament). If extended some 50 to 60 km westward beyond its terminus, lineament #5 EW would pass between the Hazelgreen and Decaturville structures.

The Decaturville circle, located in southern Camden County and northern Laclede County, is a double circle with an outer diameter of 13 km and an inner circle diameter of 5 km. The inner circle centers around the Decaturville structure, a disturbed area which appears as an exceptionally well-developed symmetrical ring structure some 4 to 5 km in diameter. The structure consists of an uplifted, intensely brecciated core 2 to 3 km in diameter with an outer zone of folded and downfaulted younger formations. A coarse-grained pegmatite with associated tourmaline-mica schist and white quartz veins is present within the highly brecciated core area. Drilling shows the pegmatite to be a 90 to 100-m thick block overlying brecciated Cambrian sediments. In addition to the massive breccia, there are numerous intrusive breccia dikes or pipes consisting of sedimentary formations in a black "mud" matrix. The intrusive breccia bodies are irregular and discontinuous in form and carry appreciable amounts of iron, lead and zinc sulfides. Opinion as to origin of the structure is divided between meteorite impact (astrobleme) and deep-seated explosion (cryptovolcano).

The Hazelgreen circle, east-central Laclede County, has an outer diameter of 9 km and an inner diameter of 5 km. The inner circle rings the area of explosive volcanism and basic dike intrusives in the basal Paleozoic formations (late Cambrian) which are known only from deep mineral tests. The outer circle coincides in part with drainage and a segment of the St. Louis-San Francisco Railroad.

Aligned with the Hazelgreen and the Decaturville circles along a northwest-southeast axis is a third double ring circle in northwestern Texas County. The outer circle has a diameter of 10 km, the inner 5 km. The three circles lie along a 70-km segment of #21 NW lineament and are approximately 30 km apart, center-to-center. A small portion of the outer circle coincides with stream drainage while part of the inner circle lies adjacent to a curved road segment. Two lineaments, #20 NW and #21 NW, pass through the circle and are parallel to but slightly offset from faults that have been mapped in the area. There are no known buried structures or magnetic anomalies coincident with the feature.

The northwestern Phelps County or "Tick Creek" double circle is one of the most prominent on the imagery. Its diameters are 9 km for the outer circle and 5 km for the inner. Both traces reflect drainage for most of their extent. Because of the area's close proximity to the University of Missouri-Rolla campus, it was used as a test site for a course in geophysical methods. Both magnetic and gravity surveys were made of a 165-sq km area covering the double circle. Stations were on 400 meter spacing. The raw data showed neither gravity nor magnetic anomalies. Derivative maps were not made.

The final circle in the South-central region is a single circle in the southwestern part of Crawford County which outlines the Crooked Creek structure, the best known of the crypto-explosive structures in the state. Diameter of the LANDSAT circle is 6 km which, in general, coincides with the polygonal ring faults that bound the structure. The Crooked Creek disturbed area consists of a highly deformed, uplifted, central core about 2100 meters in diameter circled by a "ring graben". The outer ring faults separate the structure from normal lower Ordovician formations. Vertical displacement within the disturbed area ranges upward to 400 meters. The general consensus of those who have studied these features is that Crooked Creek, as well as the other cryptoexplosive structures in the state, are the result of explosive force. As to the actual origin of the force, there is a division, with one group favoring meteorite impact and another favoring gaseous explosion from deep-seated igneous activity.

Only one arcuate trace, a double semicircle, was seen in the area. The diameters are 13 km for the outer trace and 7 km

for the inner. The curved traces are immediately to the southeast of Rolla in northern Phelps County and are open to the northwest. Although a segment of the outer trace reflects drainage, controlling factors for the arcs are not readily apparent.

Southeast Missouri: Several clusters of circular and arcuate features were observed. The area is one of thin Paleozoic cover over a sequence of volcanic (rhyolite) and intrusive (granite) rock. A large number of the circles seen on the imagery outline the igneous rock outcrop pattern. Where the basement is covered by sedimentary rock, the arcuate patterns observed on LANDSAT that reflect curved segments of stream drainage, and in part, upland topography, may have as their control the general shape of the buried igneous basement. The circular and arcuate traces may reflect features that are volcano-tectonic in origin, such as subsided cauldrons or circular plugs which resulted from Precambrian magmatic activity. Some circular features appear to be cut by others, or by faults and lineaments, implying age relationships. Large ignimbrite sheets are known to have issued from circular fractures, and intrusive bodies may also exhibit circular or arcuate patterns. The circular structures are quite distinct on the LANDSAT imagery, and while apparent on conventional air photos and to some extent topographic maps they are generally vague in comparison with traces seen on the satellite imagery. On the imagery, many of the complete circles result from a visual connection of curved valley segments with the arcuate pattern of the upland topography and cultural features -- roads, power lines, etc. A good deal more investigation and study are needed to determine if these traces reflect the record of a series of events in the evolution of the St. Francois Mountain terrain. For discussion, the traces are placed in five groups: the Marquand group, 38th Parallel group, the Taum Sauk group, the Viburnum group and the Eminence group.

Marquand group is centered in southern Madison and southeastern Iron Counties. It consists of two circles and three arcs. The larger circle, approximately 10 km in diameter, is located south of Marquand in southeastern Madison County. The smaller circle, 6 km in diameter, is located southeast of Annapolis in southern Iron County. In addition to being observed on the LANDSAT imagery, the Marquand circles have been described by Gillerman (1968) from side-looking airborne radar imagery. Also within the group are two connecting "U" shaped arcs with diameters of 10 km and 15 km located in Madison County. The arcs outline the drainage of the St. Francois River and one of its tributaries, Twelve Mile Creek. In the area of the traces, both streams are partly controlled by the Precambrian outcrop.

38th Parallel group is located in western St. Francois southern Washington and northern Iron Counties. It consists



of four circles, two of which are double or "bulls eye" circles, and one three-quarter arc. The features are essentially located along lineament #5 EW, and are concentrated in the general area of the intersection of the Simms Mountain fault system with the Palmer fault system. The semicircle is located in southeastern Washington County. It is somewhat crescent-shaped and has an approximate diameter of 5 km. Fairly large segments of the arc coincide with the drainage pattern of portions of Big River and two of its tributaries as well as parts of Missouri State Highway 32 and the Missouri Pacific Railroad. The feature essentially reflects drainage and culture.

The two single circles, both in south-central Washington County, essentially coincide with two known cryptoexplosive structures. The southern one, with a diameter of 3 km, outlines the area of the Dent Branch structure (Wagner and E. B. Kisvarsanyi, 1969), an outcrop area of late Cambrian pyroclastics associated with basic intrusives and/or diatremes. The other circle, 4 km in diameter, lies some 5 to 8 km to the north and encircles the location of the Furnace Creek structure. The structure, known only from drilling, is similar to the Dent Branch and Hazelgreen structures and, like them, is thought to have resulted from deep-seated explosive volcanism. The two double circles are located at either end of the group. The eastern one, with an outer diameter of 7 km and an inner diameter of 2 km, is located in southwestern St. Francois County, centering around the town of Bismark. The circles essentially outline a near-circular outcrop of volcanic rocks which is bounded in part by the St. Francois River, Missouri Pacific Railroad and Missouri Highway 32, all of which highlight segments of the circle. The other "bulls eye", located in northwestern Iron County, has a diameter of 2 km for the inner ring and 5 to 8 km for the outer ring, which is elongated in a northwest-southeast direction. More than half of the outer trace coincides with curved drainage patterns. The area is one of thin Paleozoic sedimentary cover over Precambrian intrusive and extrusive igneous rocks. It is possible that the circles may partly reflect a buried igneous feature.

Taum Sauk group consists of three main arcuate traces. The traces outline an igneous area, termed the "Taum Sauk Caldera" (J. E. Anderson, et al, 1969), located in northeastern Reynolds and western Iron Counties. The area includes (among others) Russell, Hogan, Vickery, Lee, Proffit and Taum Sauk Mountains. The structure covers more than 250 km and consists of more than 1,500 meters of volcanics intruded by dikes and plugs. The LANDSAT traces reflect the curved ridges and drainage patterns that both outline and lie within the structural depression.

The Viburnum Trend group consists of one double ("bulls eye") circle in west-central Reynolds County; a single circle in northwestern Iron and north-central Reynolds Counties; and a semicircle in eastern Dent and northern Reynolds Counties. The double circle in west-central Reynolds County has diameters of 10 km for the outer circle and 5 km for the inner. It is located on the Viburnum Trend (New Lead Belt) approximately midway between St. Joe Minerals' Fletcher mine and Ozark Lead Company's Sweetwater mine. Its position roughly coincides with the Bee Fork cryptoexplosive structure, one of several areas of pyroclastic rocks and associated basic dikes in late Cambrian rocks (Dent Branch, Furnace Creek, Hazelgreen). The structure has been defined from deep core drilling conducted during exploration for lead deposits. The western half of the outer trace reflects a portion of the Logan Creek drainage. The single circle located about 20 km to the north has a diameter of 14 km. Its position roughly centers around the location of the AMAX-Homestake Buick mine. The trace of the circle crosses several drainage divides, and only a small portion of the southwestern corner appears to coincide with stream drainage. Immediately to the west is a large semicircle with a diameter of approximately 25 km. If this was a complete circle, it would enclose the Buick circle. Major portions of the arc coincide with drainage.

The Eminence group is located immediately to the south of the Viburnum Trend group and is separated from it by the Ellington fault, (#15 NW). It consists of clusters of small circles and semicircles in eastern Shannon County. The most prominent traces are an 8-km-diameter circle located at the north end of the group and a 14-km-diameter semicircle in the center. This is an area of igneous knobs and the traces reflect the drainage pattern of the area as well as the roughly circular and arcuate patterns of the igneous outcrops themselves.

## 6. Analysis of IDECS/KANDIDATS Enhancement Displays of LANDSAT Imagery

LANDSAT image 1215-16121 February 23, 1973 was chosen for the detailed analysis because of the variety of geologic structure and lithologies. The image is a scene of Southeast Missouri in the St. Francois Mountains. Color and digital enhancement was done at the University of Kansas Space Technology Center, Lawrence, Kansas. Examples of enhancements are Figures IV-21 and Figure IV-22 which show portions of the LANDSAT image for the Marquand and Belleview basin areas depicting prominent circular and linear features. The enhancement is achieved by the low sun elevation angle ( $34^{\circ}$ ) and the color effect of the IDECS/KANDIDATS system. The colors enhance the drainage patterns and reveal circular features not previously noticed on the black and white standard products.

### Marquand area

On Figure IV-21, steep north-facing slopes and highways appear dark gray to black; steep south facing slopes appear yellow; and uplands, less steep areas, etc. appear pale blue and violet. The ruggedness of the terrain confines most land cover to forest and pasture. Lineaments were found to transcend the color patterns, not being limited to certain feature-color combinations. The presence of lineaments is highly suggestive by the color-drainage patterns such as a dark north-south lineament along a major drainage whereas a circular lineament may be composed of parts of all colors, i.e. terrain elements. Such enhancement techniques revealed that the linear and circular features generally contained irregularities. In addition, some lineaments were not as prominent after enhancement, and others were no longer identifiable.

### Belleview basin

Figure IV-22 highlights previously undetected lineaments trending  $N85^{\circ}E$ , which cut diagonally across the Belleview basin. The lineaments are formed by abrupt changes in color patterns which are presumably related to land cover changes, principally vegetation. Black and dark blue colors represent steep forested slopes developed chiefly on igneous rocks; the light blue and white colors are less rugged areas, and pastureland composed principally of softer sedimentary rocks. The boundary of the structural basin is distinctly outlined by contrasting tones on all but the southwestern edge where lithologic differences are not as prominent as on the remaining three sides.

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Figure IV-21  
IDECS/KANDIDATS Enhancement of the Marquand Area

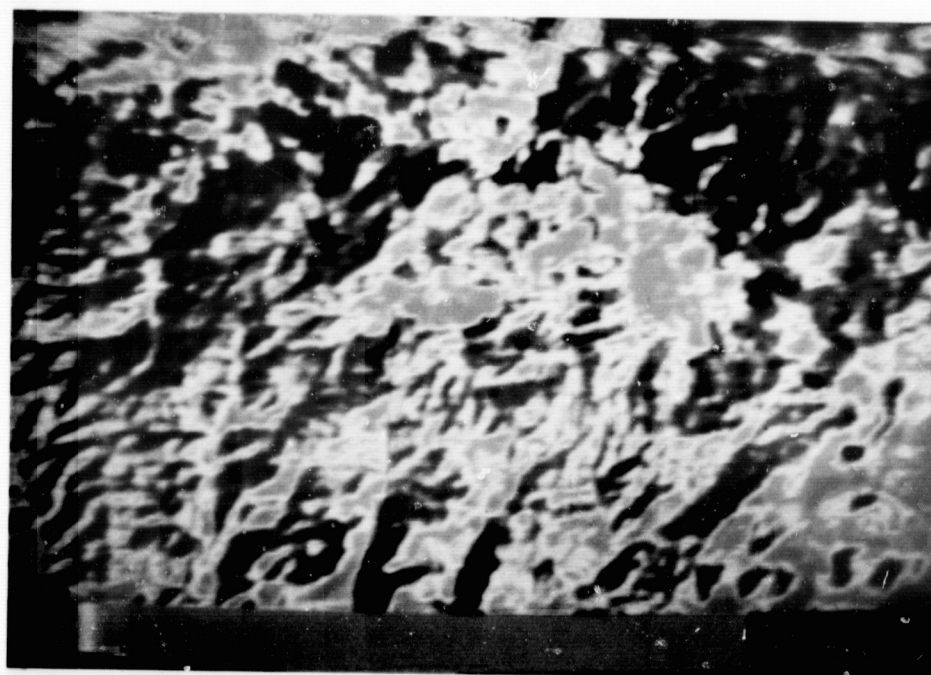


Figure IV-22  
IDECS/KANDIDATS Enhancement of the Belleview Area

### Junction of the Roselle and Annapolis Lineaments

The Roselle lineament is a north-south trending feature which aligns itself with parts of the St. Francis River. The lineament is composed almost entirely of a single color (isotonal). The St. Francis River forms that part of the lineament which extends southward into the "fish-hook" area where the lineament is formed by less prominent topographic features, yet its identity is retained by the single tonal pattern.

The very prominent 38th Parallel lineament intersects the Roselle lineament below the St. Francois River "fish hook". The lineament is formed by a tonal contrast. The Annapolis lineament intersects the Roselle lineament to the south of the 38th - Roselle intersection and intersects the 38th Parallel lineament to the east of the 38th - Roselle lineament intersection. The Annapolis lineament is exhibited by discontinuous tonal contrasts.

### Sam Baker State Park

North-south trending ridges of igneous rocks become prominent features on the color enhancement and the Roselle lineament is prominent also. There is a suggestion of a southwest-northeast lineament in the eastern edge of the scene. A previously undescribed circular feature was observed on the imagery in the vicinity of the State Park. The feature is indistinct but may reveal a buried caldera.

### Tick Creek and Gasconade River

The enhancement of the area around Tick Creek, north of Rolla, Mo., was inhibited by an overall lack of contrast in the image. Prominent circular features observed on black and white images were not observed on the enhanced images. A circular feature composed of a single tone was observed, but it was not considered distinct.

### Thomas Hill Reservoir - Moberly area

This scene enhancement contains only a few lineaments but reveals the usefulness of color enhancement in locating large water bodies and strip mines.

The most prominent lineament observed is one extending N50°E across the west branch and main reservoir area. The lineament consists of a single narrow tonal feature.

Small lakes and strip mine areas became extremely recognizable as the darker portion of the gray scale was enhanced. These features are of particular interest since the black and white image was not useful in identifying these features.



## Conclusions

The color enhancements of individual bands of imagery were not as useful as the Diazo process false-color composites of Southeast Missouri or the 35-mm slides made from the composites. However, the color enhancement of the single band images surpassed the black and white images.

In conclusion, the false-color composites enlarged by an overhead projector proved to be far superior than the color enhancements of individual band black and white transparencies.

## V. FIELD INVESTIGATIONS OF LINEAMENTS

Field examinations of a reconnaissance nature were made of selected lineaments in five areas. Comparisons of lineament traces with previously mapped structures were made for two areas. General areas of study are shown on Figure V-1. Prior to the field investigations, the LANDSAT traces were located on available topographic bases (U.S.G.S. 7½' and 15' quadrangle series). A general examination was made of the air-photo coverage to provide background on anomalous drainage and possible regional joint and fracture patterns. All available geologic data were reviewed. The areas investigated are: Areas A and B investigated by Ardel W. Rueff; Areas C, D and E by Charles E. Robertson; and Areas F and G by Ira R. Satterfield who compared lineaments with structures that he mapped recently.

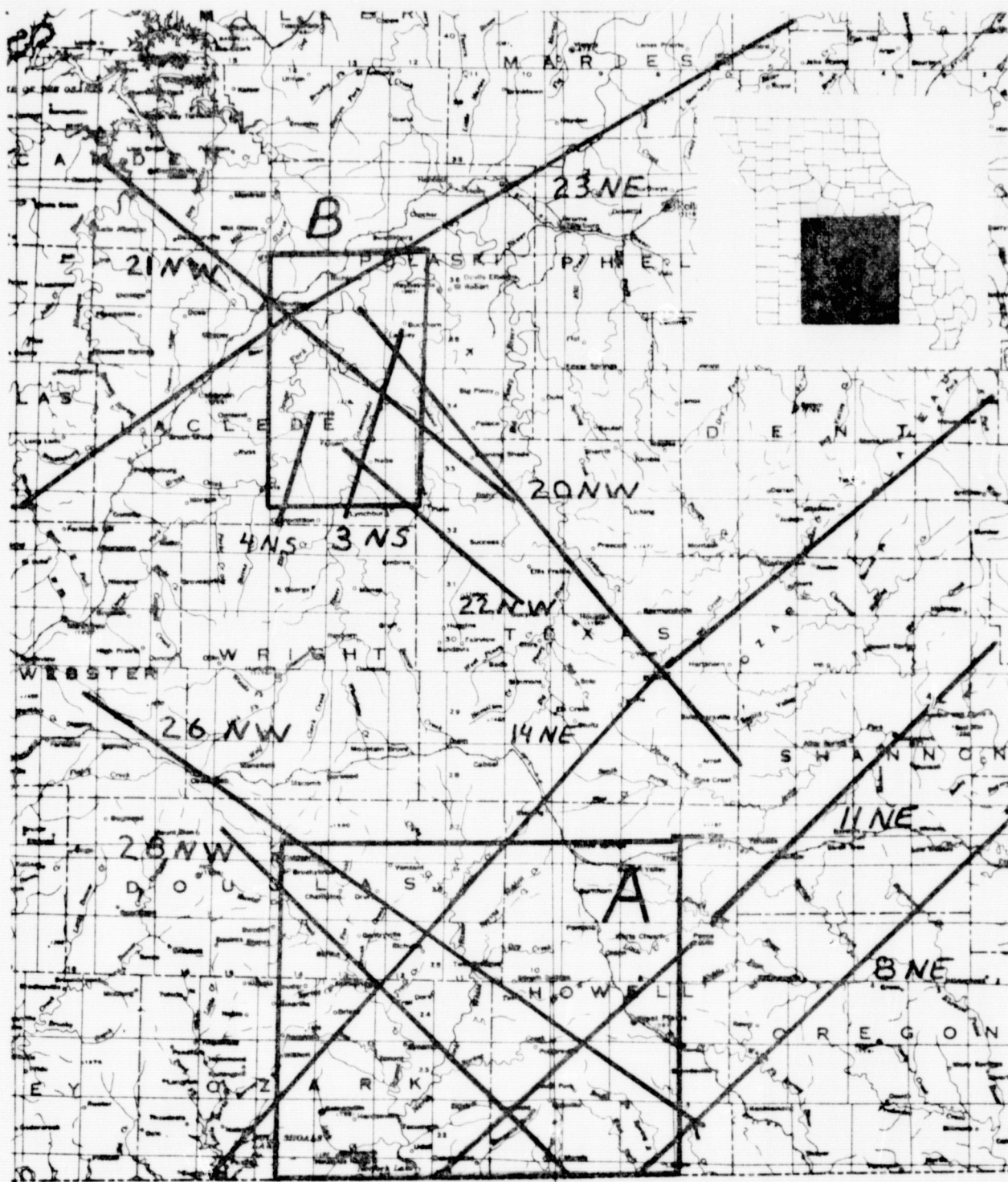
1. Area A is situated in extreme south-central Missouri and includes parts of Douglas, Ozark and Howell Counties (fig. V-2). The exposed bedrock is lower Ordovician in age and consists predominantly of cherty dolomites with lesser amounts of sandstone. The formations cropping out (from youngest to oldest) are the Gasconade (dolomite), Roubidoux (sandstone and dolomite) and the Jefferson City (dolomite). Much of the bedrock is blanketed by residuum and thicknesses of 30 meters or more are not uncommon.

Topographic map coverage for the area is in the 15' quadrangle series and consists of the Buckhart (1943), Cureall (1944), Gainesville (1934), Topaz (1939), West Plains (1944) and Willow Springs (1945) Quadrangles.

Lineament traces examined in the field were #8 NE ("Annapolis lineament"), #11 NE ("Stono lineament"), #14 NE ("Boss-Potosi lineament") and #26 NW ("Bolivar-Mansfield lineament").

The "Bolivar-Mansfield lineament" (#26 NW) extends from the southeastern corner to the northwestern corner of the area crossing the Buckhart, Cureall, Topaz and West Plains Quadrangles. The lineament crosses Fox Creek near Denlow in east-central Douglas County at a "losing" segment of the stream where surface





Scale 1:1,000,000

Figure V-2 Areas A&B, south-central Missouri



flow is being lost to the subsurface. From near Drury, also in east-central Douglas County, for a distance of 10 to 12 km south-eastward the lineament very closely parallels a recently mapped fault. Other than the above, there were no other readily apparent features seen along the trace that would indicate a major structure. The lineament should be checked in greater detail, however, as its trace does indicate an extension of the Bolivar-Mansfield fault system into this area, a distance of 100 km or more beyond its presently mapped extent.

Lineament #28 NW also extends through the area from southwestern Howell County to north-central Douglas County. The lineament has a number of features along its trace that imply that it represents a structural element. Near Trail in northeastern Ozark County, the trace crosses Trail Creek at a losing-water segment of the stream. On both the North Fork of the White River in Ozark County and Spring Creek near the Ozark-Douglas County line the lineament marks the point at which the Lower Ordovician Gasconade dolomite dips abruptly below the surface. Near Evans, in Douglas County, the lineament crosses a mapped fault at nearly a right angle. On Bryant Creek near the mouth of Brush Creek, there is evidence of minor folding in the general area of the trace. The southern part of the lineament passes through the Caulfield zinc-lead district which has minor faulting on a northwest-southeast trend.

The "Annapolis lineament" (#8 NE) passes through the extreme southeastern corner of Howell County. This is an area of thick residual cover and there were no surface indications that the trace reflects any apparent geologic condition or feature.

The trace of the "Stono lineament" (#11 NE) parallels a high voltage transmission line for a distance of about 25 km from West Plains in central Howell County to Caulfield on the Howell-Ozark County line. The trace passes through the Caulfield zinc-lead district. At its southwestern end, near Bakersfield, fractured and silicified sandstone remnants cap ridge tops which lie 1 to 2 km southeast and roughly parallel to the lineament. On Barren Creek in the southeastern corner of Ozark County, extensive outcrops of Jefferson City-Cotter dolomite show no evidence of tectonic activity.

There are no readily apparent geologic features along trace #14 NE, "Boss-Potosi lineament" to indicate that the lineament reflects structure or other surface or subsurface geologic conditions. The general area is one of limited outcrops, thick residual cover and a limited number and distribution of drillholes. The possibility that any of the traces reflect geologic conditions would entail detailed mapping and additional subsurface information. Lineaments #26 NW and #28 NW show the best correlations with known geologic structures. Lineament #26 appears to parallel a known fault and extends a major fault system (the Bolivar-Mansfield) 100 km beyond its present extent. Lineament #28 also shows correlation with known geologic features, but the relationship is not

completely understood. The other linears are not readily correlated with known features. Lineaments #28 NW, #26 NW and #11 NE are the best candidates for further study.

2. Area B is located in south-central Missouri in portions of Pulaski and Laclede Counties (fig. V-2). Exposed bedrock, cherty dolomite and sandstone is assigned to the Gasconade (oldest), Roubidoux and Jefferson City formations. Residuum is not as thick as in Area A, but is generally in the 10- to 15-meter range. Lineaments examined were #3 NS, #4 NS, #22 NE, #20 NW, #21 NW and #22 NW. The Hazelgreen cryptoexplosive structure is in the northwestern corner of the area. Topographic maps covering the area are the Brownfield, Drew, Dryknob, Ozark Springs, Richland and Winnipeg Quadrangles.

The Hazelgreen structure is located in the vicinity of the double circular trace seen on the imagery. There is an inlier of Gasconade dolomite exposed between the inner and outer rings in the northeastern part of the circle, but other than this there are no other geologic features associated with the traces. The Hazelgreen structure itself is known only from deep drilling.

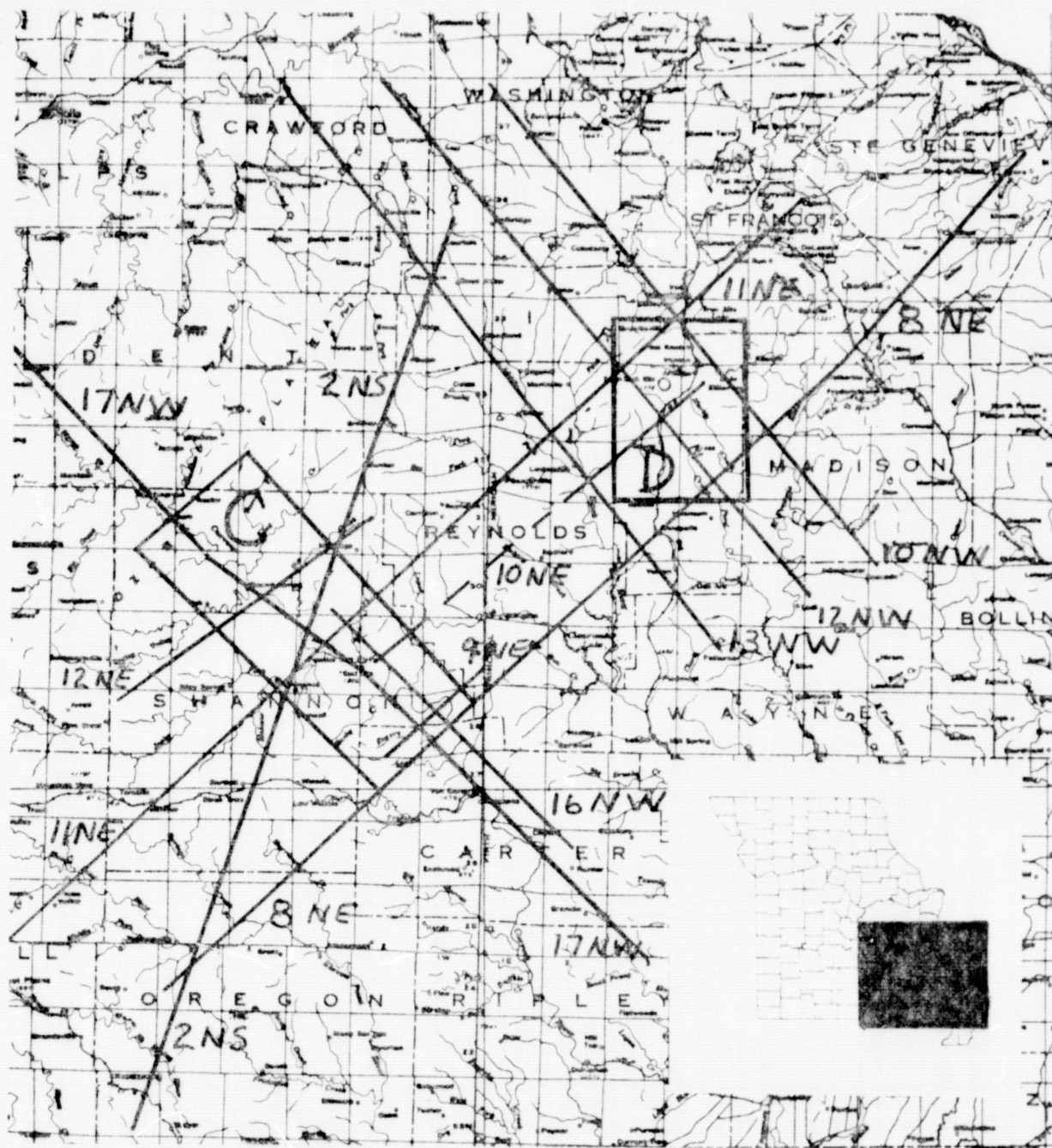
North-south lineament #3 NS intersects an area of minor faulting near the mouth of Nelson Creek, just south of the Laclede-Pulaski County line. Immediately to the north of the county line, the trace crosses the northwest-trending "County Line fault". To the south of Mill Creek, it intersects northwest-trending lineament #2 NW near an area of numerous springs on Mill Creek. The trace of lineament #4 NS intersects at an acute angle, a recently mapped northwest-trending fault, "Jacksonville fault", south of Drynob in Laclede County. Other than their intersection with the two faults and the spring concentration on Mill Creek, no other features were noted that implied structure.

The trace of lineament #22 NE passes through the northwestern corner of the area. It crosses the Hazelgreen structure and circles and intersects at right angles the northwest-trending "Laquey Hollow fault", as well as several small faults south and southwest of Richland. Along the Gasconade River east of Richland, it crosses a suspected structure but the relationship is not apparent.

Lineaments #20 NW and #21 NW both parallel and in a general sense roughly coincide with portions of two recently mapped faults. To the south of Richland, lineament #20 NW intersects the northwest-trending "Laquey Hollow fault" and parallels it for a distance of 6 to 8 km. Southeast of Hazelgreen, lineament #21 parallels the northwest-trending "County Line fault" for a distance of 8 to 10 km. The fault lies just to the north of and parallels the northwest-striking portion of the Pulaski-Laclede County line. Lineament #21 also crosses the Hazelgreen structure. In the southeastern corner of the area near Nebo, lineament #22 NW



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Figure V-3 Areas C&D, southeast Missouri

follows a rather anomalous straight segment of Mill Creek. This same reach is marked by numerous springs and is in the general vicinity of the intersection of #22 NW with #3 NS. Further to the south and northeast of Lynchburg in the southeastern corner of Laclede County, lineament #22 NW passes close to an area of minor faulting and folding. Indications of a relationship of the lineament to the structures were not apparent on outcrops examined.

In this area, as well as in others being mapped, it is becoming apparent that the LANDSAT traces point up the regional aspect of structures that heretofore have been looked on as relatively local features.

3. Area C is located along the Current River in Shannon County (fig. V-3). Lineament #17 NW ("Current River lineament") is a very strong lineament which extends from northeastern Ripley County, northward along the length of the Current River to its source, and then beyond into Miller County, just below Bagnell Dam. Total length of the lineament as observed on the imagery was 240 km. This lineament controls the drainage pattern of the Current River. It was field checked along the lower reaches of the Current River in Shannon County. This region is rugged, isolated and covered by a dense growth of timber. Much of it is inaccessible by car. Despite these obstacles, field checking revealed the following features related to the lineament.

In the vicinity of Barnett and Buttin Rock Mountains (Sec. 29, 32, 33, T. 28 N., R. 2 W.), the most noticeable structural trends strike N20°E to N50°E and are manifested in strongly developed joints. These trends are more or less perpendicular to the strike of the "Current River lineament" (#17 NW) at this point. Precambrian land forms in the area also strike northeast (Vance, Barnett and Buttin Rock Mountains). The northeast-trending limbs of the Current River bends are also related to this structural trend.

A northwest-striking structural trend is also present in the area and is manifested as shearing in Cambrian dolomite at the mouth of Sugar Camp Hollow (NE¼ SW¼ sec. 29) and as jointing or shearing of Precambrian rock to the west of Barnett Mountain. The apparently uplifted structural block formed by Vance, Barnett and Buttin Rock Mountains also has a northwesterly trend. Prominently developed jointing on Buttin Rock at the northeastern end of Buttin Rock Mountain strikes N40°E and N50°W, with less well-defined joints striking N70°W and N20°E. The northwesterly trends are parallel to the "Current River lineament".

Foliation dip and shearing on Buttin Rock Mountain trend N35°E to N50°E. Again, this is perpendicular to the strike of the "Current River lineament" and reflects a strong complementary northeast trend in the area. A prominent shear or fault zone

strikes N35°E across the southeastern part of Buttin Rock Mountain. Foliation of the associated ash-flow tuffs dip into the fault zone. Some minor iron and copper mineralization are associated with the shearing. This snear or fault zone is readily visible on aerial photographs of the area and can be seen extending southwestward across Rocky Creek Valley and up the eastern flank of Mill Mountain.

Weak fracturing on Coot Mountain (Sec. 22, T. 29 N., R. 3 W.) is probably related to the "Current River lineament". Quartz veins and some shearing on Jerktail Mountain (Sec. 5, T. 29 N., R. 3 W.), may also be related to this lineament. Springs along the Current River, such as Montauk, Round, Blue and Big, are probably related to fracturing along the "Current River lineament."

Other localities visited in the general area included Buzzard Mountain Shut-in and Thorny Creek Canyon. At Buzzard Mountain Shut-in (Sec. 6, T. 28 N., R. 2 W.), two prominent joint trends were observed in Precambrian rhyolite (N50°E and N55°W). A shear zone striking N50°W containing quartz veins was noted on the eastern wall of the Shut-in. This shear zone is parallel to the trend of the "Current River lineament".

At Thorny Creek Canyon (Sec. 29, T. 29 N., R. 2 W.), which is located on the lineament trace, two prominent structural trends were observed. At the northeastern end of the canyon, foliation in Precambrian ash-flow tuff strikes N45°W parallel to the Current River lineament. Jointing in the ash-flow tuff strikes N45°W and N45°E, again reflecting the same structural pattern of the entire area.

In summary, it appears that the structural grain of the region surrounding the "Current River lineament" consists predominantly of northeasterly and northwesterly trends manifested as joints, foliation dips, shear zones and faults. The "Current River lineament" itself appears to be a major zone of weakness in the earth's crust along which shearing, prominent jointing and faulting occurs. It is crossed in places by lineaments that are perpendicular to its trend.

The major contribution of ground-truth investigations along this lineament was the discovery of faulting and shearing in the area. Detailed mapping of the area would undoubtedly reveal a complex structural pattern.

4. Area D, located essentially in central Iron County (fig. V-3), has two principal lineaments, #12 NW ("West Bellevue-East Sabula lineament") and #10 NE ("Hogan lineament"), which were studied in the field.

The "Sabula lineament" has been field checked from Crane Mountain (Sec. 8, T. 32 N., R. 4 E.) northwestward to the western flank of Ketcherside Mountain (Sec. 26, T. 33 N., R. 3 E.). This

strong lineament trends northwestward through the St. Francois Mountains and, in the Crane Mountain area, defines the northeastern boundary of the Sabula Basin. The lineament is marked in the area by a bold southwest-facing escarpment of Precambrian lava flows and welded tuffs which stands 150 meters or more above the Sabula basin. The basin itself is developed on Cambrian sedimentary rocks and the difference in elevation of the top of the Precambrian from the escarpment to the basin is about 450 meters. The trachyte porphyry on Crane Mountain is fractured and sheared and is locally mildly propylitized. The major fracture traces are oriented subparallel to the face of the escarpment and to the "Sabula lineament". The steepness of the escarpment, fracturing, rock alteration and difference in elevation to top of Precambrian all suggest that a normal fault separates this escarpment from the Sabula basin.

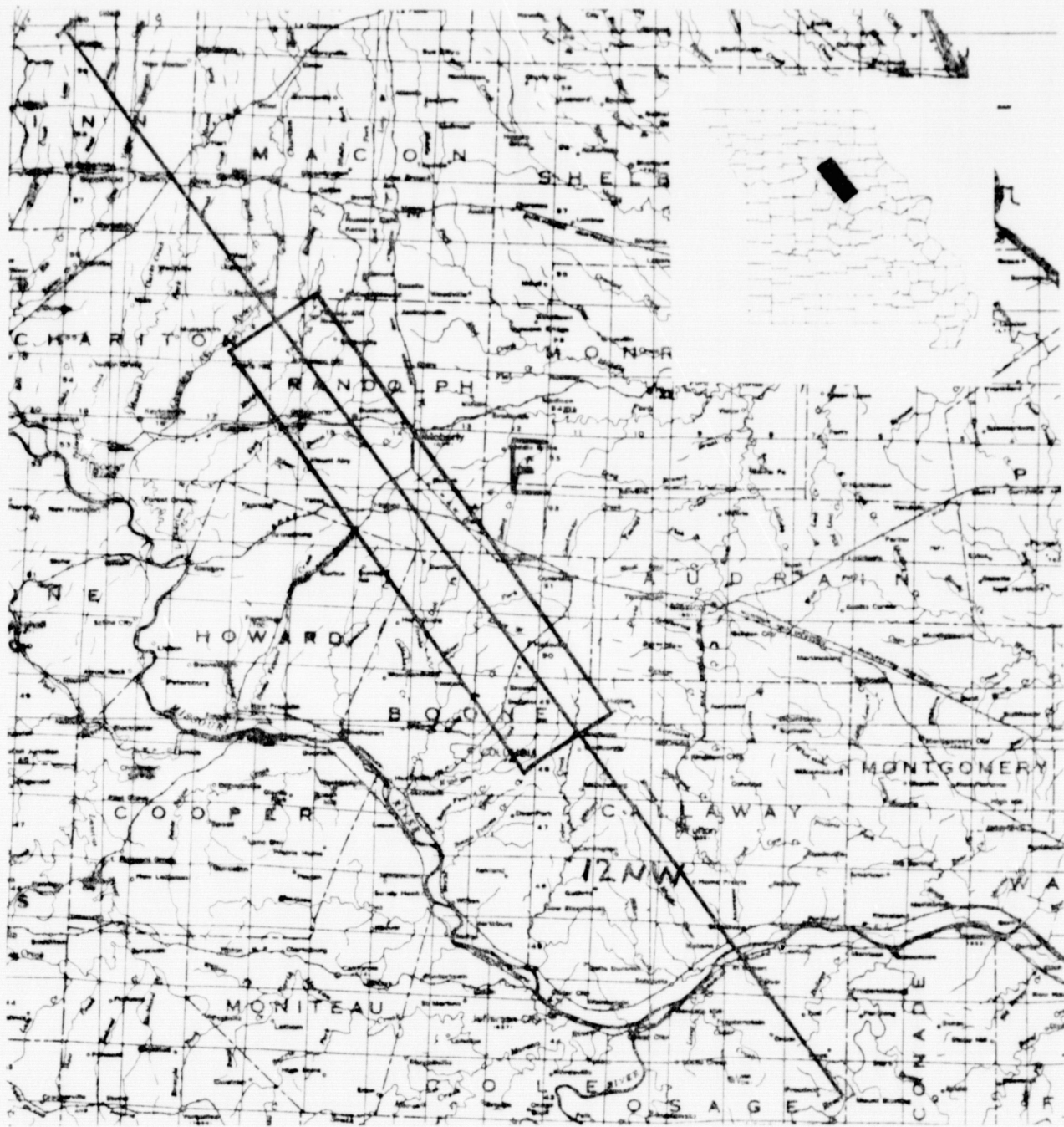
The second trace, the "Hogan lineament" has been field checked in the southeast quadrant of the Ironton 7½-minute quadrangle from near Hogan (SE¼ sec. 27, T. 33 N., R. 3 E) to beyond Cuthbertson Mountain (Sec. 19, T. 33 N., R. 4 E.). In this area, the lineament trace trends north-northeast across Ketcherside Mountain and across the southeastern face of Cuthbertson Mountain. The most striking features along the lineament trace are the copper deposit at Ketcherside Gap (NE¼ sec. 36, T. 33 N., R. 3 E.) and the manganese deposits on Cuthbertson Mountain. Field investigations at the latter locality indicate that the manganese deposits are part of a larger area of manganese mineralization that trends northeasterly across Cuthbertson Mountain and is parallel to the lineament trend. The copper deposits at Ketcherside Gap may be associated with a northeasterly trending fault in that area. These relationships are indicative of a geometric relationship between mineralization and the lineament trace.

Vertical compaction foliation indicating structural deformation was observed on the southern slopes of Ketcherside Mountain (SW¼ SW¼ sec. 25, T. 33 N., R. 3 E.) precisely along the trace of the "Hogan lineament" as mapped. Micro-shear zones were also observed at this locality.

A parallel zone of shearing and possible structural deformation follows the valley of Big Creek from Hogan northward through the Royal Gorge. Zones of shear, with preferred directions of strong jointing and areas of weak iron and manganese mineralization, are present both east and west of Royal Gorge.

5. Area E, located in the north-central part of the state is along the northern extension of lineament #12 NW ("West Bellevue-East Sabula lineament"). The lineament crosses the Missouri River in the vicinity of Mokane in Callaway County, extends through Huntsville in Randolph County and crosses into Iowa, north of Saline in northwestern Mercer County. Area is shown on Figure V-4.





Scale 1:1,000,000

Figure V-4 Area E, north-central Missouri



Geologic mapping in southern Randolph County, northwestern Boone County and northeastern Howard County has shown this segment of the lineament to be related to relatively sharp northwest-trending structural flexures.

Southeast of Rucker, the lineament appears to be manifested as the steep southwestern limb of the northwestern segment of the Browns Station anticline. To the northwest, between Rucker and Higbee, it appears as the steep northeastern limb of a northwesterly-trending synclinal trough. North of Higbee the structural relationships become obscure but the lineament appears to correspond to another though a weakly-developed northwesterly-trending synclinal area.

6. Areas F and G, in central Missouri (Figure V-5), were mapped recently so a comparison of the mapped structures was made with the traces observed on the LANDSAT imagery. The discussion deals, primarily, with the geologic setting and structure and, secondly, with the relationship of the structure to the traces or lineaments observed on the LANDSAT imagery. The geology of Area F was mapped by Larry Stout (a former Survey employee and Satterfield) for a study of the drainage basins within the outlined area. The mapping is classified as reconnaissance and it was done at a scale of 1:62,500. The geologic mapping of Area G is also classified as reconnaissance and was done on a 1:24,000 scale base. The principal objective of the investigation was to test a slightly different method of mapping bedrock units and was confined essentially to the Safe 7½' quadrangle.

General Geologic Setting of Area F: This area comprises all of Camden and parts of Morgan, Miller, Pulaski, Laclede and Dallas Counties. The surface expression of the geology reveals that the northern half of the area is located over a Precambrian high. There is approximately 500 meters of rock between the top of the Roubidoux and the Precambrian in this area. Prior to the investigation, only the Red Arrow fault, the Proctor anticline, and the Decaturville structure were known. The bedrock units that crop out in the area are the Eminence Formation, Cambrian in age; The Gasconade Formation, Roubidoux and Jefferson City Formations, all Ordovician in age; minor amounts of Mississippian strata in the southern part; and Pennsylvanian strata in the north. The Cambrian and Ordovician rocks are predominantly cherty dolomite and some sandstones, the Mississippian cherty limestones and the Pennsylvanian -- mostly sandstones and shales.

Area F Structures: As previously mentioned, the quality of the geologic mapping in the area is classified as reconnaissance and is at the 1:62,500 scale; thus, in many cases the locations of structures are only approximate and could be off as much as 0.4 km. Presently 21 faults, 2 anticlines (which possibly could be connected) and a very strong lineament from the air photos have

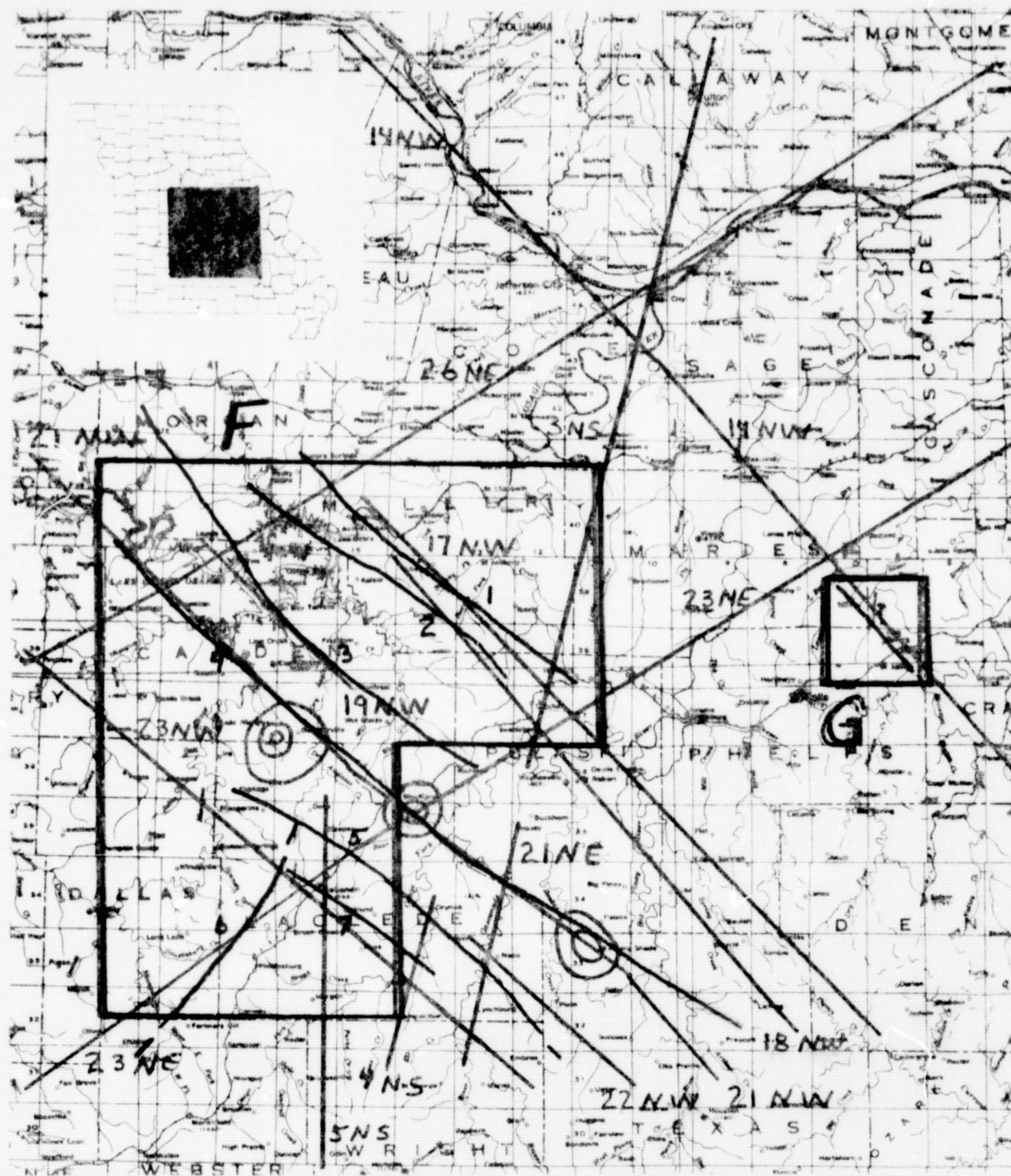
been mapped within the area. In addition to field observation of several faults, most of them are seen as strong lineations on the air photos as well as on the aeromagnetic maps of the area. Vertical displacements on the faults range from 20 meters to 45 meters on the larger one and 15 meters or less on the smaller ones. Although displacement on the larger faults is relatively small, it is suspected that several of them are rejuvenated basement faults that were active during deposition of the Cambrian and Ordovician sediments. Supporting data for this conclusion are the abrupt lateral changes in the lithology of the formations near these faults. The deepseated fault concept may also be supported by the magnetic lineaments so prominent on the aeromagnetic maps, as well as the suggestive changes in the basement rock types along the faults. With the exception of one northeast-striking fault in the southern part of the area, all others have a northwest-strike. Dye tracing in the area indicated that there is a substantial loss of surface water at the intersection of the faults with the streams.

Comparison of LANDSAT lineaments to mapped structures within the area shows that all or parts of six of the mapped structures coincide with the LANDSAT lineaments. A strong lineation (#7) from air photos coincides with imagery lineament #23 NW. Structures numbered #1, #2, #3, and #4, located in the northern half of the mapped area, all strike in a northwest-southeast direction. These faults can also be observed on air photos as lineaments and are expressed on the aeromagnetic maps. Structures #3 and #4 coincide with LANDSAT lineaments #19 NW and #21 NW. Structure #5 does not coincide with a LANDSAT lineament within the area, but does parallel in juxtaposition with lineament #22 NW to the southeast. Structure #6 is the only mapped structure in the area that strikes NE. In part, it coincides with LANDSAT lineament #23 NE. Structure #6 is also apparent on the air photos. Structure #7, a strong air photo lineament, probably represents a small flexure or shear zone with no displacement, although deformation might possibly have occurred outside the mapped area.

The Decaturville structure was mapped recently by the USGS and was not remapped during this study. This structure makes circular traces on the LANDSAT imagery as well on the air photos, but is not indicated on the aeromagnetic maps.

General Geologic Setting of Area G: The area lies essentially within the Safe 7½' quadrangle in the northeastern part of Phelps County and the southeastern part of Maries County. The exposed bedrock in the area consists of sandstone and cherty dolomite of the Roubidoux and Jefferson City Formations (Ordovician age) and some sandstone and shale of Pennsylvanian age. Prior to the investigation, no structures were known to cross the Safe quadrangle area.

Area G Structures: Bedrock mapping of the Safe quadrangle revealed a northwest-striking asymmetrical anticline with a possible fault on the northeastern flank. The relief on this structure is in the vicinity of 15 to 23 meters. Study of the aeromagnetic maps and air photos for the area reveal only a slight suggestion of a structure. Comparison with the LANDSAT lineament map showed the structures to parallel the "Grand River lineament" (#14 NW), one of the longest observed, with the axis of the fault essentially coinciding with the trace of the lineament.



Scale 1:1,000,000

Figure V-5 Areas F&G, central Missouri

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## VI.

### RELATIONSHIPS OF LINEAMENTS, CIRCULAR FEATURES AND MINERALIZATION

#### 1. Statewide Pattern

LANDSAT data has the potential of being a major tool in the study of the earth's geologic framework and mineral wealth. A major use for satellite imagery of immediate concern is in the development of a better understanding of the origin and distribution of metallic mineral deposits (metallotects) and as a guide to regional exploration.

Comparison of LANDSAT traces with the distribution of major mineral deposits in Missouri shows a close association (Figures IV-5, IV-10, IV-15, IV-20, VI-1, VI-2, VI-3, VI-4 and VI-5). Mineralized areas in the southern part of the state are found on or along lineaments, near the intersections thereof, and associated with circular and arcuate traces. The frequency and distribution of lineaments are most regular and repetitive in the area of the Southeast Missouri Mining District. A definite lineament pattern is also associated with the formerly productive southwest Missouri part of the Tri-State Mining District and with the Central Missouri District. Along the Arkansas-Missouri border, several smaller mineral deposits occur near the intersections of lineaments in intensely brecciated rocks.

The greatest density of lineaments is observed in the area of exposed and shallow Precambrian basement in Southeast Missouri (Figures IV-2, IV-7 and IV-12). Both in southwest and central Missouri the relatively dense lineament pattern occurs over buried Precambrian highs as indicated on the contour map of the buried Precambrian surface (E. B. Kisvarsanyi, 1975). The density of lineaments in Missouri therefore appears to be inversely proportional to the depth of the Precambrian surface. The Precambrian basement, as a tectonic unit, must have exerted a profound influence over igneous activity, mineralization, and structural movements throughout the history of the region.

A number of lineaments correspond to faults or fault systems mapped in the Precambrian rocks and in the overlying sediments (Figures IV-3, IV-8 and IV-13). The lineaments frequently extend on strike beyond the mapped lengths of faults. Many of the lineaments, however, are not associated with mapped faults and may alternately be coincident along their strikes with drainage patterns, topographic escarpments, igneous-sedimentary contacts, zones of mineralization, intrusions of diabase dikes, and brecciation. Many are believed to be expressions of deep-seated fracture-fault systems in the Precambrian basement, and their width on the ground surface may be measured in hundreds or even thousands of meters.



In Missouri, good correlation exists between the linear, circular, and arcuate LANDSAT traces and the major magnetic anomalies (Figures IV-4, IV-9, IV-14 and IV-19). Aeromagnetic maps, where available, frequently display excellent magnetic lineaments. In central Missouri, a prominent aeromagnetic lineament corresponds closely with one of the major northwest-trending lineaments, identified from the imagery, which passes through the Decaturville Structure. Recent mapping indicates that several faults in this area are along strike with this lineament (Figure V-5). In many places, deep drilling indicates that the magnetic anomalies are caused by mafic intrusive bodies in the Precambrian basement (E. B. Kisvarsanyi, 1974). Coincidence of a string of magnetic anomalies in northern Missouri with the Grand River lineament, and coincidence of another series of magnetic anomalies west of St. Louis with a major northeast-trending regional lineament strongly suggest deep-seated structural control. The distribution of Precambrian iron-ore deposits in Southeast Missouri is also expressed by magnetic anomalies and shows correlation with lineaments identified from the imagery.

Circular and arcuate features are particularly abundant in the area of exposed and shallow basement in Southeast Missouri and often tend to be clustered in areas underlain by volcanic rocks (Figure IV-17). Where these rocks are exposed, as in the area of the Taum Sauk Caldera west of Ironton, and east of Eminence, the circular pattern is also visible on 1:24,000-scale topographic maps and on stereo images of airphotos. Circular features over buried basement are in part defined by curving segments of stream channels; others appear to encircle isolated small outcrops of volcanic rock around sediment-filled depressions. Some known cryptoexplosion structures also appear on the LANDSAT imagery as circular features. Several circular and arcuate features have been observed along the Viburnum Trend. The circular features may be volcano-tectonic in nature, subsided cauldrons or circular plugs, and appear to be related mostly to a mechanism of Precambrian magmatic activity. Some ignimbrite sheets may have issued from circular fractures and intrusive bodies may also exhibit cylinder-like circular patterns. Some circular features appear to be cut by others, or by faults, representing some age difference. It is possible that some circular features are of different origin and are genetically related to mineralization. Detailed ground-truth investigations are needed to determine the importance of these features in the evolution of the St. Francois terrane and to determine their role, if any, in mineralization.

## 2. LANDSAT Lineament Metallotects

The relationship of the LANDSAT linear traces to metallic mineral deposits in Missouri is shown on Figures VI-1, VI-2 and VI-3 (1:1,000,000 scale maps - attached). In general, circular traces are not suggestive of a distinct relationship with mineralized locations but rather are an expression of

exposed Precambrian igneous features or a reflection of their influence on drainage and/or topography developed on younger sediments.

In comparing the LANDSAT lineaments with metallic mineral deposits, fairly definite relationships are apparent. In general, these can be classified as:

- a. Individual deposits or clusters along a single lineament,
- b. Deposits located at the intersection of two traces,
- c. Triple junction deposits or clusters,
- d. Quadruple junction deposits, and
- e. Deposits lying within or along the boundaries of traces that form geometric patterns, chiefly polygons.

The association of mineral deposits with lineaments or their intersection(s) is most obvious in the southern half of the state. The greatest number of metallotects are recognized in the Southeast Missouri Mining District which is also the area of greatest concentration of lineaments. A large number of lead-zinc deposits are concentrated in the Southwest Missouri Mining District (Tri-State), but observable traces on the LANDSAT imagery of the area are sparse. In general, northeast-trending lineaments display the best relationship to the spatial distribution of mineral deposits. Following are examples of the five deposit-lineament relationships. Examples of intersection and shape relationships are shown on Figures VI-4 (southwestern Missouri) and Figure VI-5 (southeastern Missouri).

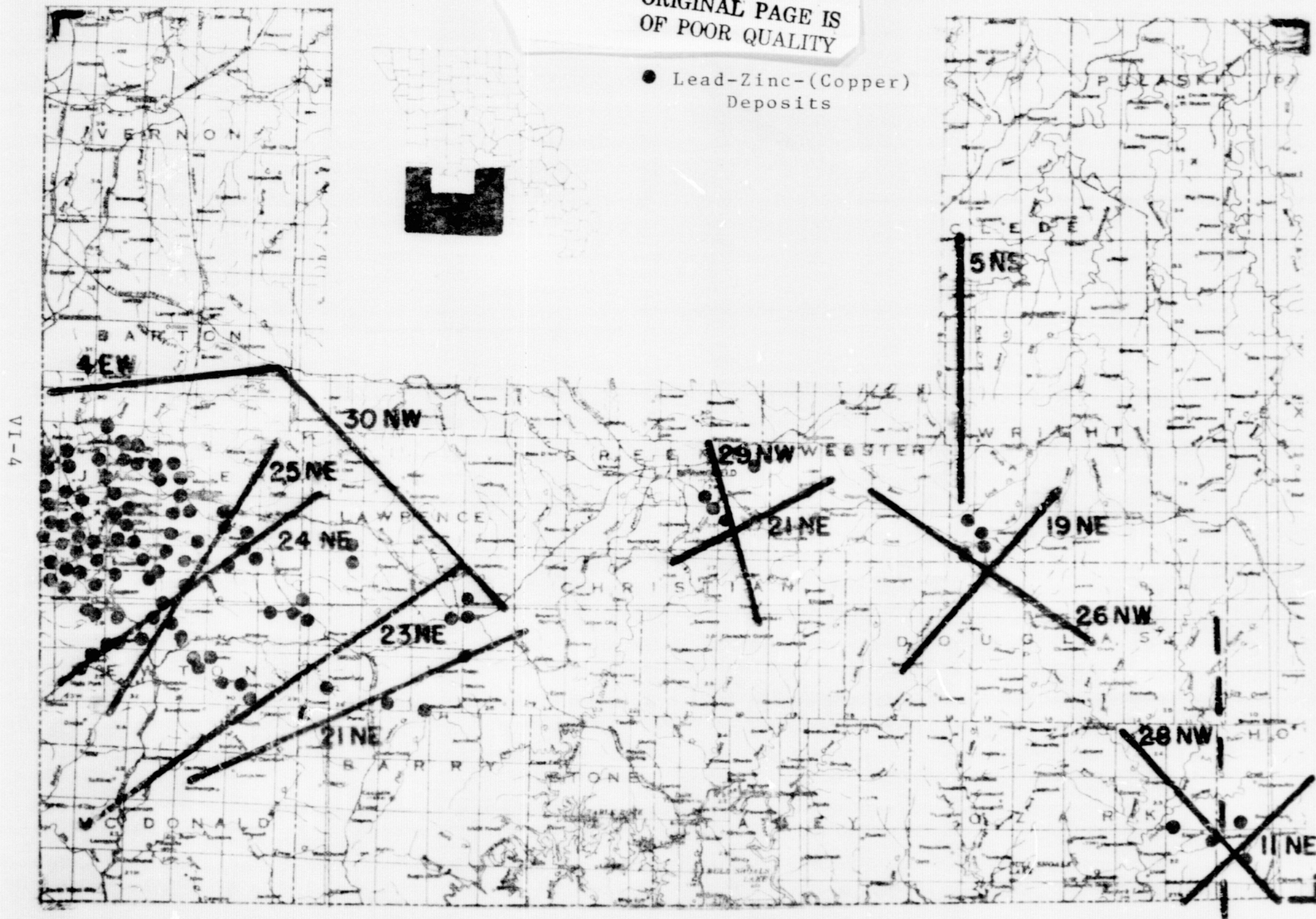
a) Single lineaments:

The northeast trending lineaments have the largest number of mineral deposits along their courses. Examples are #11 NE and #24 NE (Figure VI-1). Few of the northwest, north-south or east-west trending lineaments are coincident with mineral deposits. The best examples of those that do have mineral occurrences along their trace are #7 NW, #11 NW, #2 NS and #5 EW (Figures VI-2 and VI-3). Mineralized areas along #2 NS are in Shannon, Reynolds, and Iron Counties. Adjacent to the trace are the lead mines of Ozark Lead Company, St. Joe Minerals, AMAX-Homestake, and Dresser-Cominco. While classed as lead mines, these deposits have significant zinc, copper, and silver mineralization. In addition to the mines, several copper deposits are along the trace in central Shannon County. Near the north end of the lineament, the Boss Precambrian magnetite-copper deposit lies immediately to the west.

Lineament #5 EW, the 38th Parallel lineament, has two major clusters of lead-zinc mineralization along its trace. The largest is the "Old Lead Belt" district in the Bonne Terre-Flat River-Elvins area of central St. Francois County. The other, to the west in the Palmer area of southwestern Washington County, has barite mineralization in addition to lead and zinc. The main zone of mineralization along this

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● Lead-Zinc-(Copper)  
Deposits

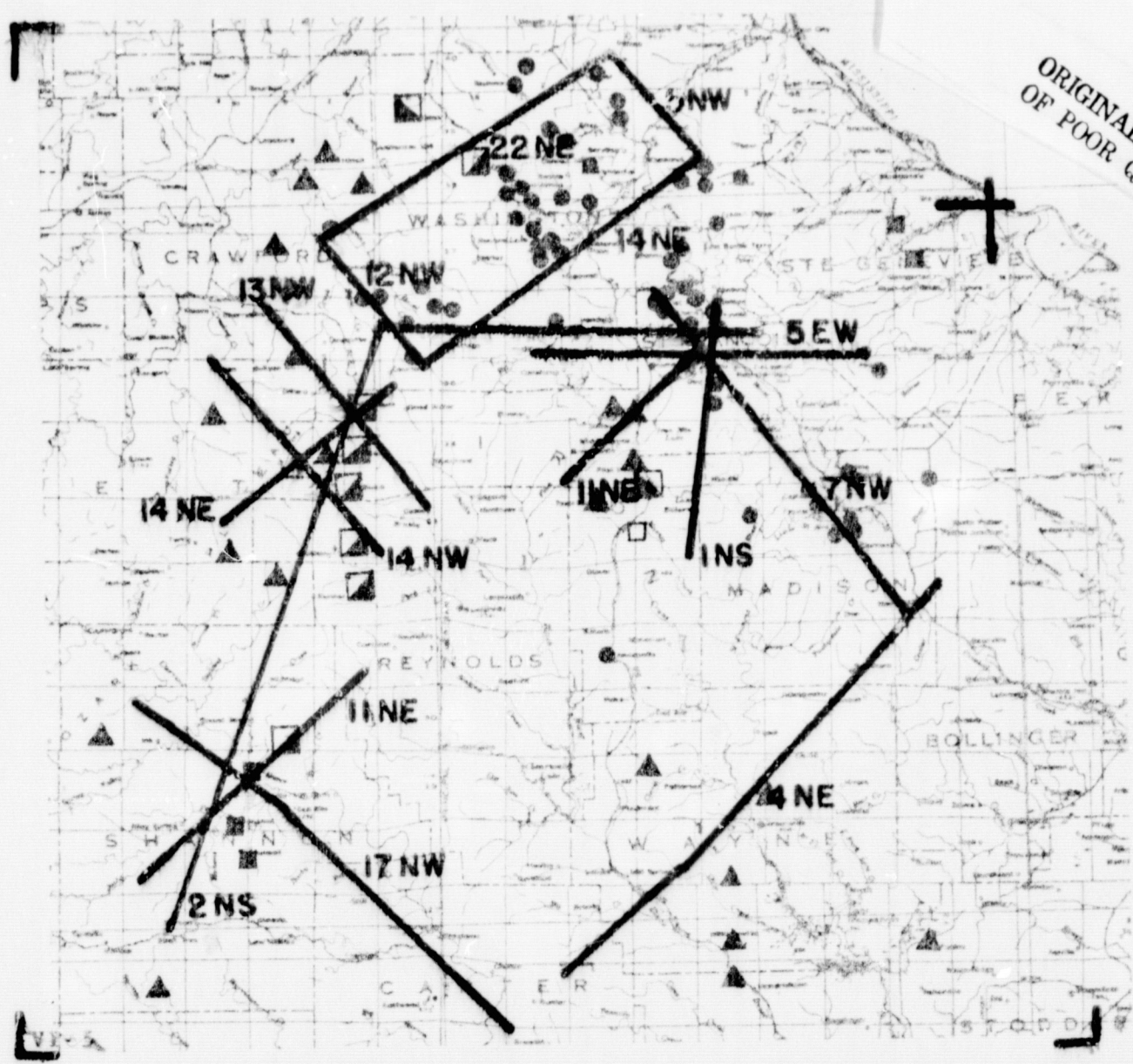


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Figure VI-4 Lineament-mineral deposit relationship (junctions & polygons)  
Southwest Missouri



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- Lead-Zinc-(Copper) Deposits
- ▲ Iron Deposits
- Manganese Deposits
- Copper Deposits
- ▤ Lead-Zinc-Copper Mine
- ▥ Iron Mine

Scale 1:1,000,000

Figure VI-5 Lineament-mineral deposit relationship  
(junctions & polygons) Southeast Missouri

trace is bounded on the east by the Roselle lineament (#1 NS) and on the west by lineament #2 NS.

Lineaments #7 NW and #11 NW both pass through major areas of mineralization. #7 NW extends from the Fredericktown lead-zinc-cobalt-nickel deposits in northeastern Madison County through Mine LaMotte to the "Old Lead Belt" in central St. Francois County. Only the central portion of trace #11 NW is associated with significant mineralization. The trace passes through the Washington County Barite District (Potosi) which also has lead mineralization and extends westward to St. Joe Minerals' Indian Creek lead mine and to the east of a magnetite deposit at Meramec Mining Company's Pea Ridge mine in northwestern Washington County.

The two northeast trending lineaments are in the southeastern and southwestern parts of the state, respectively. Lineament #11 NE in the southeast extends from the Arkansas line in Ozark County, northeast to St. Francois County. Mineralization is present along portions of the trace for its entire extent. At the southern end are the zinc deposits of the Caulfield District. The central segment in Shannon County passes through the Eminence copper occurrences and just to the southeast of the Ozark Lead Company's mine (lead-zinc-copper-silver). At its northeastern end, the trace passes near several Precambrian iron deposits and the abandoned Iron Mountain mine of the Hanna Mining Company. The trace terminates in St. Francois County where it lies at the southeastern end of the main part of the "Old Lead Belt". Lineament #24 NE in the Southwest Missouri Mining District (Tri-State) has zinc-lead mineralization along its trace in Newton, Jasper, and Dade Counties. Although the alignment of many of the deposits in the Tri-State is suggestive of both northeast and northwest trends, no LANDSAT traces were observed to coincide with them.

b) Double junctions:

There are several excellent examples of mineral deposits clustered at or near the intersection of two lineaments (Figure VI-4). In northern Newton County, lineaments #24 NE and #25 NE intersect in the southern part of the Tri-State Zinc District. At 100 km and 150 km to the east, two other double junctions lie at approximately the same latitude. One, located in southeastern Greene County, is at the intersection of lineaments #21 NE and #29 NW. The intersection is in the area of the Pierson Creek deposits which are predominantly zinc with minor lead mineralization. The other is located in southwestern Wright County in an area of minor lead and zinc mineralization. It is formed by the intersection of lineaments #19 NE and #26 NW. Extension of lineament #5 NS 10 to 15 kilometers to the south would make this a "triple junction deposit". A fourth double junction deposit is the Caulfield Zinc District in southwestern Howell County.



Lineaments forming the intersection are #11 NE and #28 NW. This deposit might also qualify as a "triple junction deposit" as the faint trace of a possible north-south lineament, shown only on the composite map of all traces (Figures VII-1 attached), passes through the deposit. In addition to the above cited examples, there are a number of "double junction deposits" that could be described in the southeastern quadrant where the bulk of the observed lineaments are located.

c) Triple junctions:

A number of three-lineament intersections of triangular areas are located in the Southeast Missouri Mining District (Figure VI-5). Only two potentially qualifying examples are located outside the district. These are cited under the double junction discussion - southwestern Wright County (Cedar Gap) and southwestern Howell County (Caulfield). The three-lineament junction in northwestern Iron County centers at the town of Viburnum. It is a point intersection formed by lineaments #2 NS, #13 NW and #14 NE. The addition of lineament #14 NW forms a small triangular area with the apex, formed by the triple junction point to the northeast. The point intersection is at the approximate location of St. Joe Minerals' Viburnum mine-mill (Mine #28) complex. The triangular area roughly includes the Cominco-Dresser Magmont mine and the AZCON-Getty Boss deposit. As stated elsewhere, the mines are dominantly lead mineralization with significant zinc, copper, and silver mineralization in recoverable quantities. The triple junction in Shannon County is a triangular area formed by lineaments #2 NS, #11 NE, and #17 NW. The apex points to the southeast and the area outlined is one of minor copper mineralization.

d) Quadruple junctions:

A prominent quadruple junction is present just south of the main area of mineralization in the "Old Lead Belt" (Figure VI-5). The junction is a small triangular area formed by the intersection of lineaments #1 NS, #5 EW, #11 NE, and #7 NW. The junction centers near the town of Doe Run in south-central St. Francois County where there are several worked-out lead mines.

e) Polygonal patterns:

Two types of linear traces fall into the category of forming polygonal patterns. One type forms the boundaries of major mining districts or large clusters of mineral deposits; the other type has a significant number of mineral deposits along its boundaries. Lineaments in the latter category also fall into the single lineament group. Two excellent examples of the first type, boundary lineaments, are present. One is in the Southeast Missouri Mining District and the other is in the Southwest Missouri Tri-State District.

The entire Missouri portion of the Tri-State Zinc District is bounded by lineaments (Figure VI-4). The north boundary is formed by lineament #4 EW, the east by #30 NW and the south side by either #21 NE or #23 NE. The west boundary is a nearly north-south striking lineament located in Kansas

and Oklahoma. A number of small zinc deposits are present along both #21 NE and #23 NE. In southeastern Missouri (Figure VI-5), the major portion of the Washington County Barite District lies within a rectangle extending from the southwestern part of Washington County northeastward into southwestern Jefferson County. Mineralization within the area is barite, lead, and zinc. The boundary of the rectangle is formed by lineaments #14 NE, #22 NE, #5 NW, and #12 NW. Mining areas and deposits within the rectangle are the Palmer, southwestern Washington County, and Potosi, central Washington County, barite deposits and mines and the Valles Mines (abandoned), southwestern Jefferson County, and St. Joe Minerals' Indian Creek (active), Washington County, lead mines. The Richwoods barite deposits in northeastern Washington County and the Pea Ridge Precambrian magnetite iron deposit (Meramec Mining Company) in northwestern Washington County lie just to the northwest of the north bounding lineament (#22 NE).

An example of the second type of polygon, i.e., mineral deposits along the bounding lineaments, is a large five-sided figure in Southeast Missouri (Figure VI-5). It is formed by lineaments #5 EW, #2 NS, #17 NW, #4 NE and #7 NW. Metallic mineral deposits are located principally along lineaments #5 EW, #2 NS and #7 NW. The mines and deposits of the "Old Lead Belt" lie along the northeastern side of the polygon (#7 NW) with the Fredericktown (Madison County) deposits -- lead with associated cobalt-nickel-copper mineralization at the southeastern end and the major Bonne Terre-Flat River mines (abandoned) at the north where lineament #7 NW intersects with #5 EW. Other areas of major mineralization - principally along the perimeter of the polygon are located at the junction of #5 EW with #2 NS - the Palmer district barite deposits with minor lead-zinc mineralization and along the extent of #2 NS which lies along and adjacent to the Viburnum Trend or "New Lead Belt". Within the polygon are the Precambrian magnetite deposits and mines at Iron Mountain (abandoned) and Pilot Knob (active), the Annapolis lead mine (abandoned) and the major portion of the Precambrian manganese district.

The relationship of LANDSAT traces (lineaments) to structural features and known metallic mineral deposits in southern Missouri is quite good. The traces probably reflect basement structures and as such add to our knowledge of the tectonic framework of the state. Many no doubt represent zones of weakness - faults and fractures - and may have played an important role in the movement of mineralized fluids and acted as an ore-control in the concentration of deposits. A number of known mineral deposits are located along lineaments and at lineament intersections. That linear and circular traces coincident with known geologic structures can be observed on the LANDSAT imagery, the synoptic view of the imagery that permits regional evaluations, and the rather good correlation of lineaments and

lineament intersections with areas of known mineralization all combine to point up the value of multispectral imagery as a guide to mineral exploration.

3. Tectonic features of the Metallogenic Provinces of Southeast Missouri

An important phase of structural analysis is the recognition of metallogenes, particularly the tectonic controls of ore deposits in metallogenic provinces. Southeast Missouri is the site of two major metallogenic provinces of North America. One of these is the Precambrian iron-copper-manganese province and the other is the Mississippi Valley-type lead-zinc-copper province with associated cobalt-nickel mineralization in the Paleozoic sediments. The Washington County barite district, residual deposits of iron and pyrites, and veins of tin, tungsten, silver and lead are also within the area. The relationship of faults, folds, other structural lineaments and LANDSAT linears to the mineralization and Precambrian outcrops of southeast Missouri is shown on Figure VI-6.

The spatial association of linear, circular and arcuate features as identified from the multispectral imagery, with the major iron and lead-zinc-copper deposits of the Southeast Missouri Mining District is illustrated in Figures VI-7 (lineaments) and VI-8 (circular & arcuate). The Precambrian outcrop area of the St. Francois Mountains is centered around the town of Ironton. The lead-zinc-copper deposits of the Viburnum Trend Mining District are located along an approximate north-south line, about 40 km east of Salem.

The ore deposits of the Precambrian igneous province are localized along fractures and faults, and the strata-bound lead-zinc-copper deposits are concentrated at the hinge zones of Precambrian structural highs and lows. The influence of the Precambrian basement on the stratabound mineralization has been discussed by G. Kisvarsanyi (1977). Faults and fractures brecciated sedimentary rocks and controlled the movement of mineralizing solutions. The residual barite deposits are localized along fracture zones in the carbonate host rocks. A distinct relationship is recognized between the distribution of kimberlite-alnöite dikes and diatremes and the structural lineaments of the Avon area. Such a system of interrelationship between major structural lineaments and alkaline ultramafic complexes has been demonstrated in Angola and other parts of Africa (Reis, 1972).

Comparison of the pattern of structural lineaments and the pattern of lineaments identified from the LANDSAT imagery shows a basic similarity of strike directions and spacing. Precambrian outcrops in the St. Francois Mountains and Eminence areas have an orthogonal to polygonal distribution pattern. Within the outcrops, square-shaped basins and highs developed by differential tectonic movements. Structural lineaments form

OLD DOTT FRAME

# LEGEND

- ⊗ Mine
- × Prospect or minor occurrence
- Fe Iron
- Mn Manganese
- Pb Lead
- Zn Zinc
- Cu Copper
- Ni Nickel
- Co Cobalt
- Py Pyrite
- Ba Barite
- Ag Silver
- W Tungsten
- U Uranium
- Th Thorium

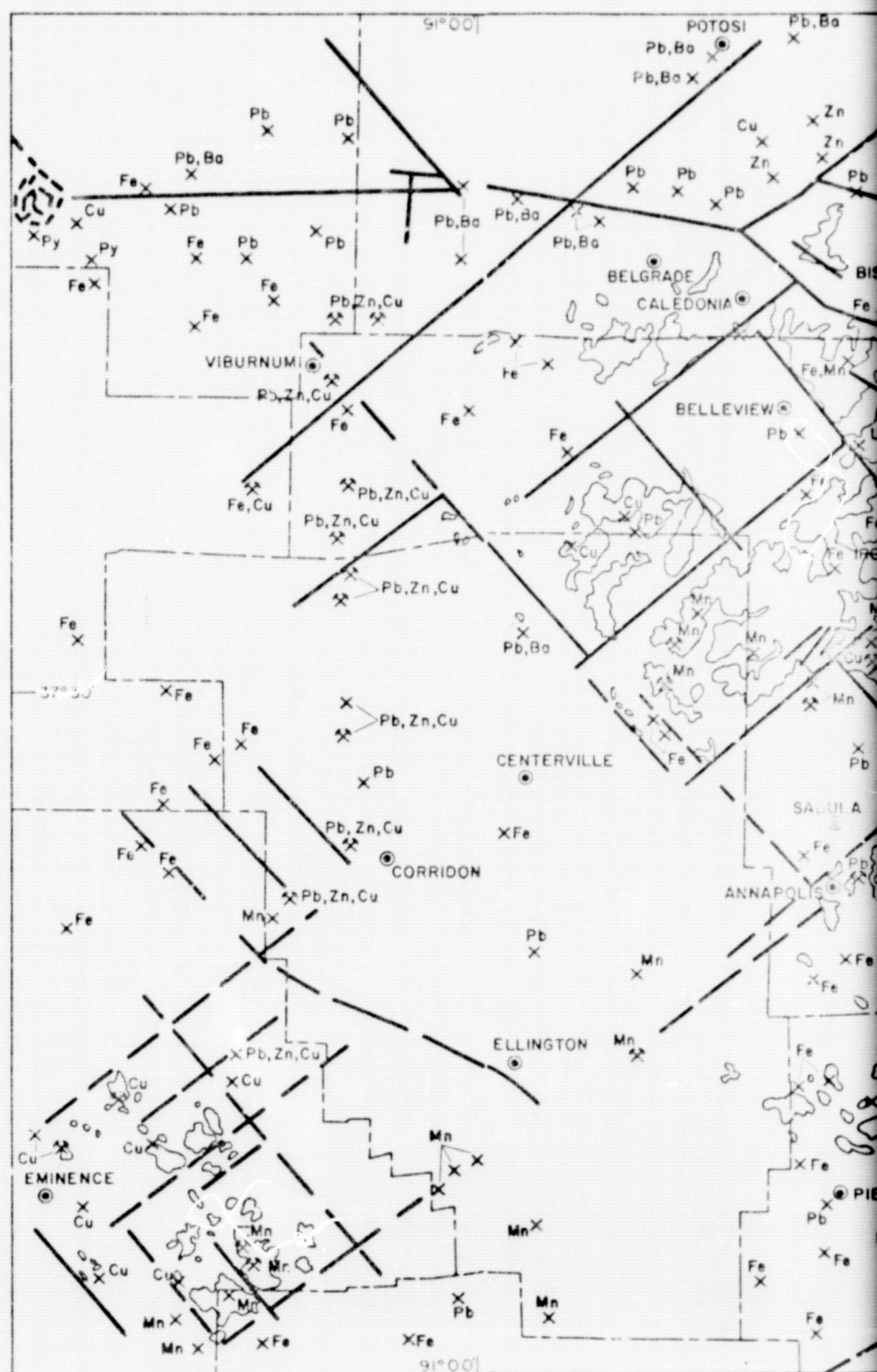
--- Structural lineaments including mapped faults

◊ Precambrian outcrops

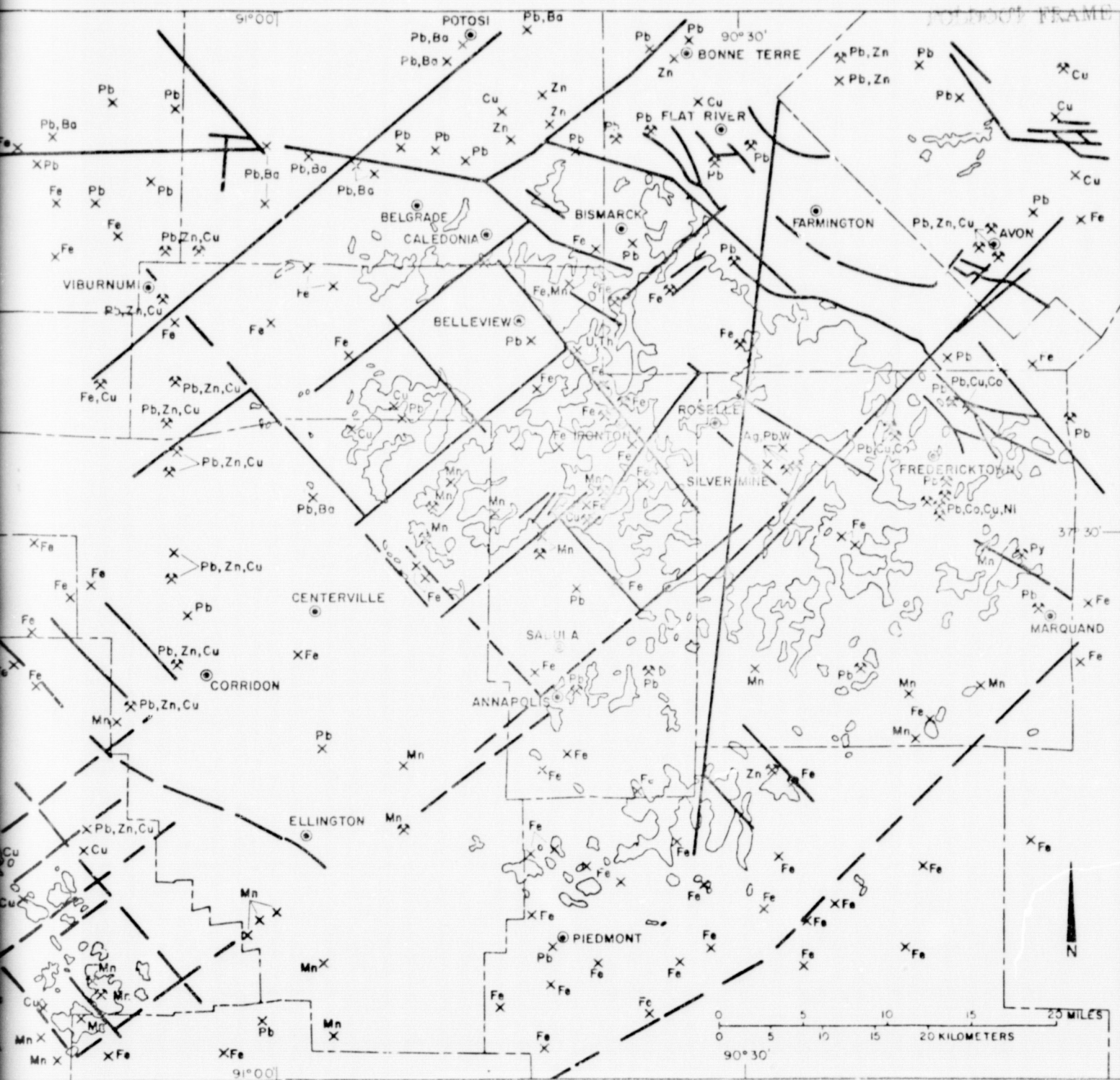
Figure VI-6

Structural lineaments, Precambrian outcrops and mineralization in Southeast Missouri

(G. & E. B. Kisvarsanyi 1976)









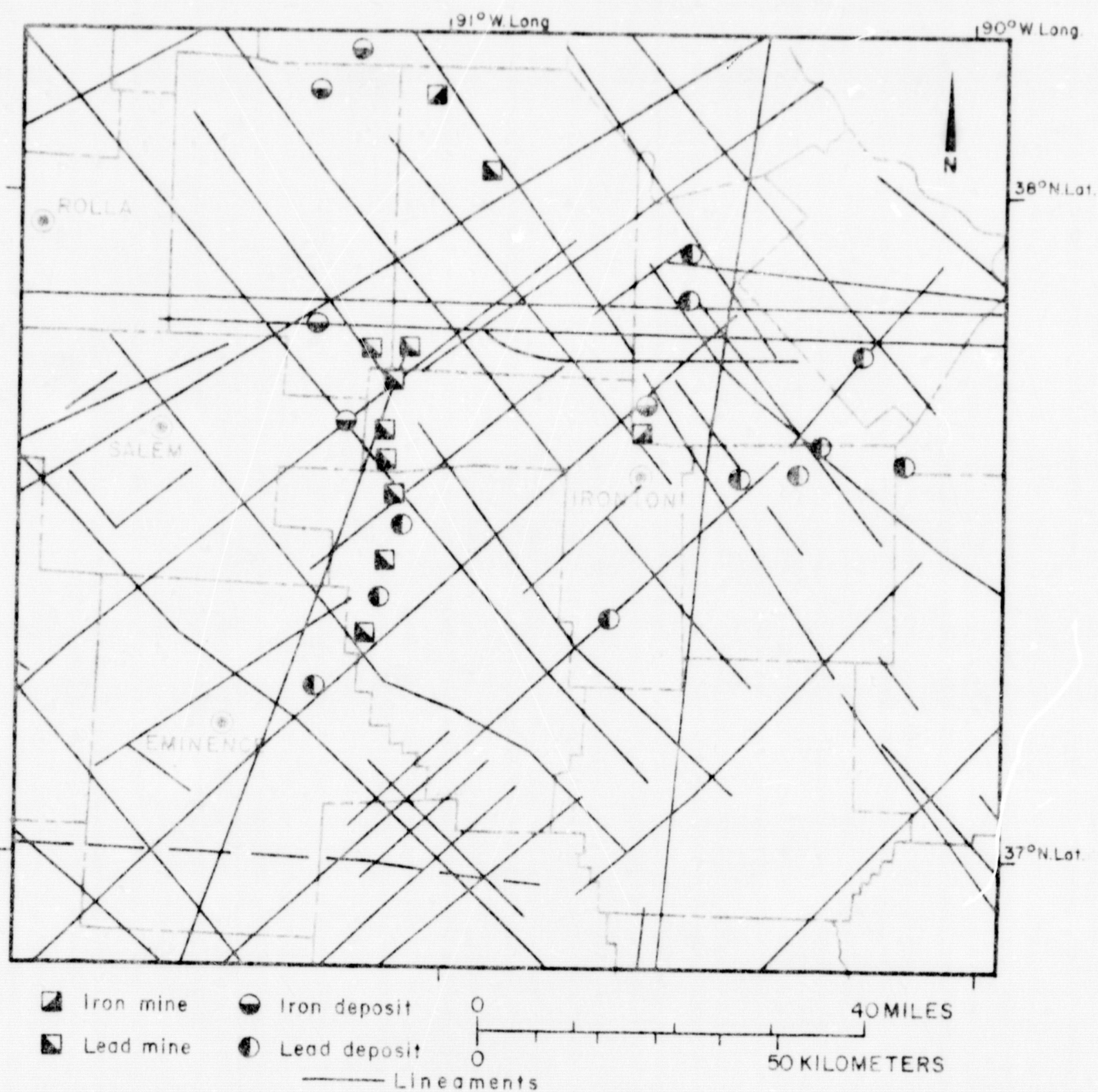


Figure VI-7 Lineaments in the Southeast Missouri Mining District (G. & E. B. Kisvarsanyi, 1976)

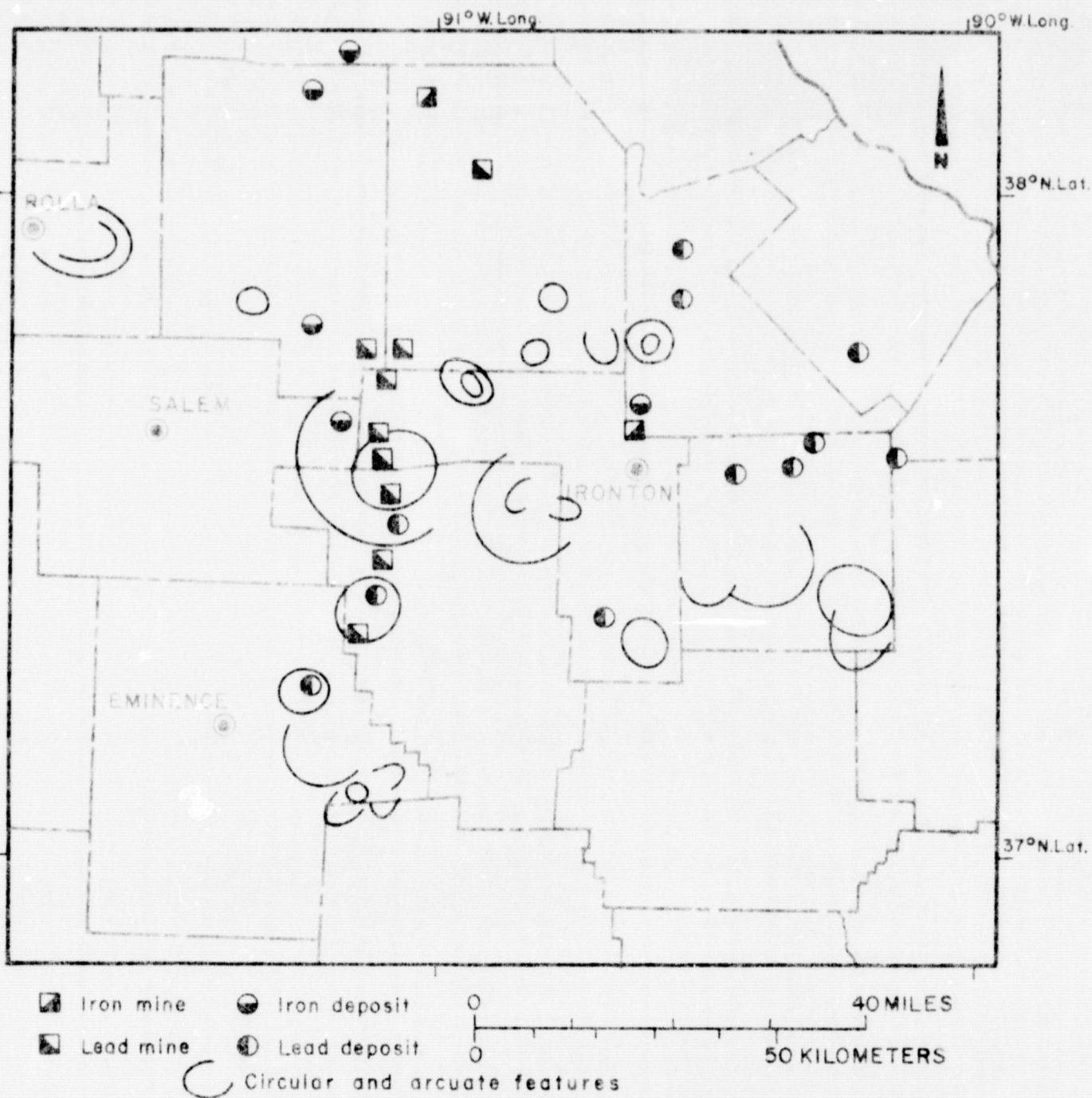


Figure VI-8 Circular and arcuate features in the Southeast Missouri Mining District (G. & E. B. Kisvarsanyi, 1976)

the boundaries of tectonic units such as the down-dropped blocks of the Belleview and Sabula "basins" and the uplifted Eminence block. A detailed description of the structural lineaments, many of which have been named, is given by Kisvarsanyi and Kisvarsanyi (1976).

In order to bring the interrelationship of tectonic elements and mineralization into sharper focus, minor concentrations of metals (prospects and "shows") in both the Precambrian and the Paleozoic rocks have been plotted on the structural-lineament map of Southeast Missouri along with the important mineral deposits (Figure VI-6). The distribution of mineralization shows a degree of coincidence with the structural lineaments of the region, which in turn appears to be a function of its Precambrian structure. The fracturing and faulting of the Precambrian basement have created an intricate plumbing system which provided avenues of access for metal-bearing solutions in Precambrian and later time. Such a system might permit ascending solutions to reach favorably prepared (fractured, brecciated, etc.) host rocks, lateral migration and redistribution of metals, and control of descending ore fluids along fractures produced by Precambrian and Paleozoic epeirogeny.

Local and regional structural elements had an important role in the formation and localization of the ore deposits of the region. Careful analysis of the individual lineaments and their patterns in the region should be a useful exploration tool.

Further investigations are needed to establish the interrelationship of ore deposits with the lineaments observed on the satellite imagery. Geographic association alone may not be meaningful if the genetic relationship of lineaments and ore emplacement is absent. Furthermore, the emplacement of ore deposits may be controlled by smaller structural elements which are not visible on satellite imagery. The association of lineaments and ore deposits may be closer, or better displayed in the Precambrian ore deposits than in the strata-bound deposits. In the latter, factors other than structure, such as the Lamotte pinchout, permeability of sediments, chemical environment, etc., had also influenced ore deposition.



## VII. SUMMARY: APPLICATIONS AND SIGNIFICANCE

This study of the regional lineaments, which puts the geologist on the observation platform of the satellite, is based on electronic and optical registration of electromagnetic waves and the transfer of millions of discontinuous and repetitive input data onto a piece of black and white film. The mental process of individual scientists in "analyzing" these "prints" is that of cognition-recognition-registration-interpretation and application of data. This process neither can be complete nor comprehensive in totality at any given moment of a geological investigation. Furthermore, in the discovery and recognition of the nature and characteristics of the lineaments and their interpretation, much depends upon the observation of very subtle tone and texture changes and thus much depends upon the skill, endurance and knowledge of the individual dealing with them. The process of apperception first involves intensity and geometry; that is, the recognition of existence of something different on the "pictures" and that they have certain size, dimensions, length, width and direction. The second level of recognition is that of the organization of these elements in a pattern. The third level of recognition involves interpretation; that is, creative imagination of the mode and mechanism of motions of the earth's materials in space which created the linear or curvilinear features. In geology these processes are faulting, fracturing and differential erosion-transportation of particles or compounds. The deduction of the stress field, the cause of motions adds a new dimension in the understanding of crustal processes. The establishment of time relations will add up to the dynamic evolution in space and time of this particular segment of the earth's crust which generated the structural complexity, part of which are the lineaments. Finally, spatial, genetic and temporal relationships of the lineaments to any other features such as mineral and energy resource deposits or rock bodies may decipher a distinct part of the geologic history of the region. Therefore, it should be recognized that studies in this stage are the beginnings of what shall become a routine tool for all geological work.

There is no doubt that satellite image analysis has contributed much to our geologic knowledge, the most significant contribution being the increased understanding of the regional structural framework of the area. The major lineaments are structural and exhibit deep-reaching zones of weaknesses. They are mostly large fracture zones, representing Precambrian basement structures, some rejuvenated, that recurrently fracture the overlying sedimentary veneer. The major structural lineaments have a profound influence on rock-type distribution, topographic features, drainage systems and subsurface hydrology. Some features apparently controlled the emplacement of mineral deposits as well as the evolution of structures connected with hydrocarbon production. The lineaments are commonly, or partially, coincident with major faults mapped in the Paleozoic formations or coincident with synclinal and anticlinal axes. They may control superimposed porosity-permeability to such a degree that movements of fluids, groundwater, connate or formational water,

spring locations and cave formations are influenced by them. Ore-forming solutions may not have escaped their effects in the past since they may have been the avenues of ore solution transport. In fact, large scale solution breccias in the carbonate rocks may have developed along major structural lineaments or intersections thereof.

The repetitive nature, frequency, azimuthal directions, as well as the enclosed angles, dimensions and signs of basement rock deformations point toward the probability that the majority of lineaments are of Precambrian age. Some of these were subsequently rejuvenated and moved in connection with the uplift of the Ozark Dome in Paleozoic time. Seismo-tectonic processes of the New Madrid area could result in recent movement along the lineaments in south-east Missouri.

Significant results: Major linear, circular and arcuate traces observed on LANDSAT imagery of Missouri are shown on State base maps at 1:1,000,000 scale (Figure VII-1 lineaments & Figure VII-2 circle & arcs). Both figures are attached. Only lineaments in excess of 20 km in length were considered since the shorter traces, generally reflecting ridge tops and single stream segments, can best be studied on conventional and high altitude aerial photographs. Lineaments plotted fall into three categories: short 20 to 50 km; medium 50 to 150 km; and long 150 km plus. The longest (#12 NW & #14 NW) within the state boundaries are nearly 500 km in length. Several extend into adjoining states.

Lineament plots indicate a distinct pattern and in general follow the major structural trends. The dominant directions (NE - NW - NS - EW) mostly reflect structural features of the Precambrian basement of the Platform. Coincidence of lineaments traced from the imagery and known structural features in the state is high, thus supporting a causative relation between them. The lineament pattern apparently reveals a fundamental style of the deformation of the intracontinental craton. This is one of the most important contributions of imagery study which enabled the investigators to delineate dozens of heretofore unknown linear features which are related to epeirogenic movements and deformation of this segment of the Continental crust. It is anticipated that the LANDSAT lineament map of Missouri will prove to be valuable in a variety of geological studies including exploration planning for natural resources.

Recognition of a large number of major linear and circular features on the imagery represents a great forward step in understanding the outstanding geological-structural features of the state. Although the most spectacular area of linear display is in southeast Missouri in the area of the St. Francois Mountains and south of the 38th parallel north latitude, some important lineaments are seen and traced into the drift-covered northern part of the state.

The major contribution of ground-truth investigations along selected lineaments is the discovery of faulting and shearing in



the areas in question. Detailed mapping along all major lineaments would undoubtedly reveal complex structural patterns near their course. Frequently, there are changes in the lithology of the formations near these faults. The deep-seated fault concept also appears to be supported by the magnetic lineaments so prominent on aeromagnetic maps, as well as by the suggestive changes in basement-rock types along the faults.

Lineaments in general are expressed on the ground as combinations of geomorphologic features, faults, fracture zones, escarpments, and axes of synclines and anticlines. Often they express major Precambrian zones of tectonic weaknesses, loci of stock and dike intrusions, and lithologic changes coincident with the pattern of magnetic anomalies. Coincidence of lineaments traced from imagery and mapped structural features is high and supports a causative relationship between them. Lineaments and mineralization are interrelated in a geometrically classifiable pattern.

The dimensions of the lineaments and their relationships to major fault-fracture zones in the Precambrian basement and in the Paleozoic sediments raise the question of their significance as avenues of ore-fluid systems. Movement of ore-bearing fluids along these zones could involve mobilization of metals from both the mantle (kimberlite pipes, cryptoexplosive structures) and Paleozoic sediments resulting in Ni-Co-Cu enrichment of mineral deposits. Brines depositing Mississippi Valley-type ore may have moved along these structural lineaments and the study of ore localization and exploration programs should employ the results of this work. Recent geochemical surveys along the Annapolis lineament (#8 NE) in Madison County have disclosed strong tin and lead anomalies with copper and zinc haloes in soil samples (Gustavson, J. B., International Oil & Gas, Inc., Memphis, Tennessee, oral communication).

The role of major structural lineaments should be studied in regional hydrogeologic investigations. The distribution and pattern of caves, springs, hot springs, and the movement of groundwater may be strongly controlled by the structural lineaments.

Quantitative image analysis revealed some lineaments not recognized by photogeologic study. The combination of color-original and gradient IDECS display was the most useful in comparing details with black and white transparencies. Edge enhancement was successfully used to differentiate and amplify analog signals in order to discriminate boundary information and increase contrast contained in an input image. Analysis of the printouts of quantized and enhanced images has brought out some linear segments better than the original black and white transparency, but the overall quality of printouts is such that it is difficult to evaluate them if one does not know the lineaments beforehand.

The color enhancements of individual bands of imagery were not as useful as the Diazo process false-color composites or the 35 mm slides made from the composites. However, the color

enhancement of the single band images for the most part surpassed the black and white images. The false-color composites enlarged by an overhead projector proved to be far superior than the color enhancements of individual bands or black and white transparencies. Small lakes and strip mine areas, often indistinct on black and white product, were highlighted and easily identified on color enhancements.

Some of the lineaments have been found to represent cultural features such as highways, railroads, electric transmission and pipelines. Others reflect both straight and curved drainage segments and ridges. What these traces reflect in areas where they cannot be related directly to known geologic structures, bedrock, topography, drainage or culture is difficult to determine. That the imagery does have the propensity for highlighting certain patterns is useful in that the feature being accentuated may well reflect blind geologic features such as folds, faults and basement or magnetic highs. Continuing analysis of the imagery features and their relationship to surface and subsurface conditions is warranted in on-going and future studies.

There are a number of studies and products that will utilize the results of this investigation. Two studies in progress that will incorporate and further develop these data are the U. S. Nuclear Regulatory Commission study of the New Madrid seismotectonic area and a cooperative U. S. Geological Survey-Missouri Geological Survey study of the Rolla 1° x 2°, 1:250,000 map series (fig. VII-2). One important aspect of these studies is the attention directed to possible structural features in the state and in adjacent states, the solution of which will bring further understanding of our geologic framework. Systematic exploration of geological resources has to be based upon geological concepts. Structural lineaments, of necessity, will be part of those concepts.



Figure VII-3

Investigations utilizing LANDSAT data

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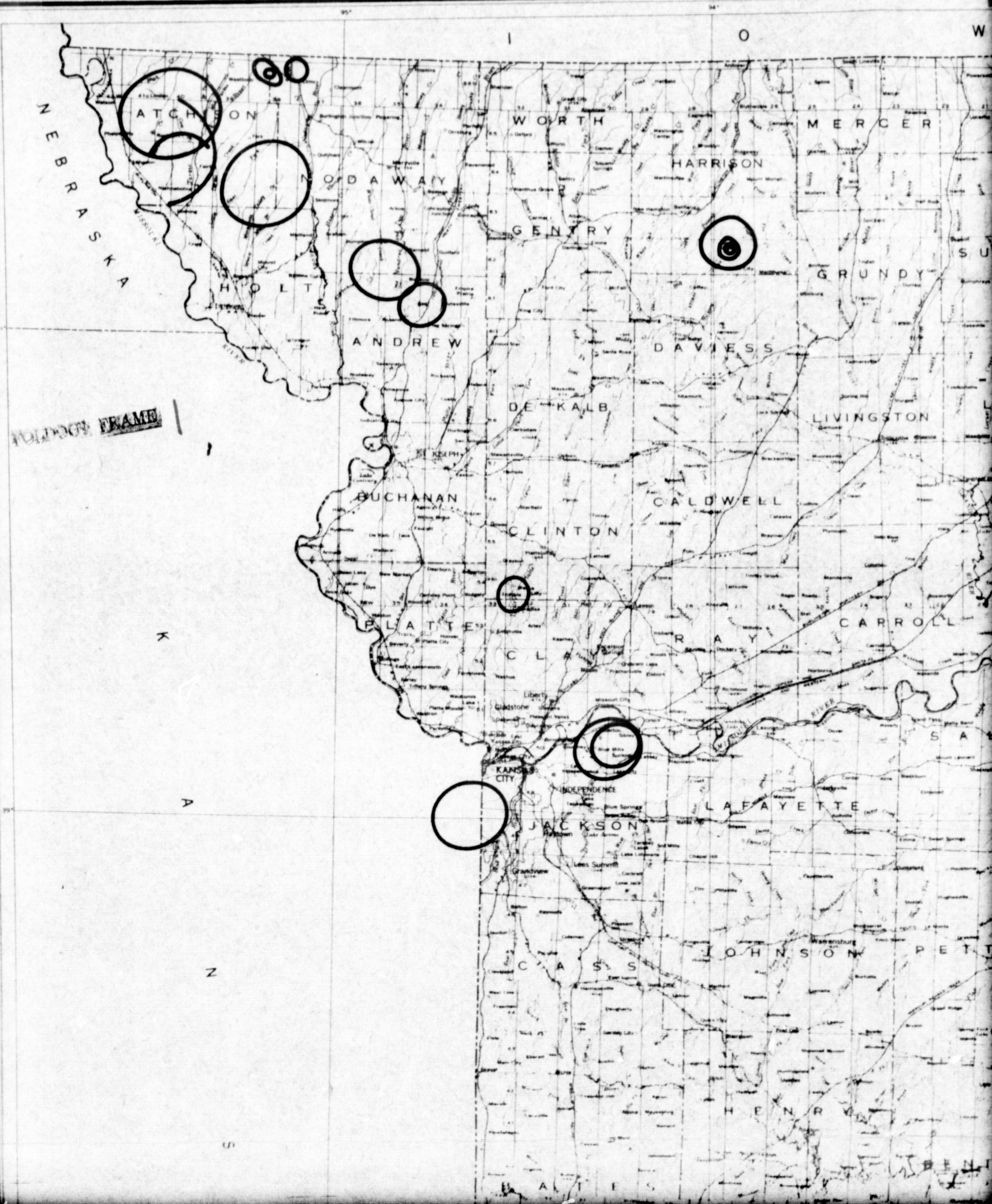
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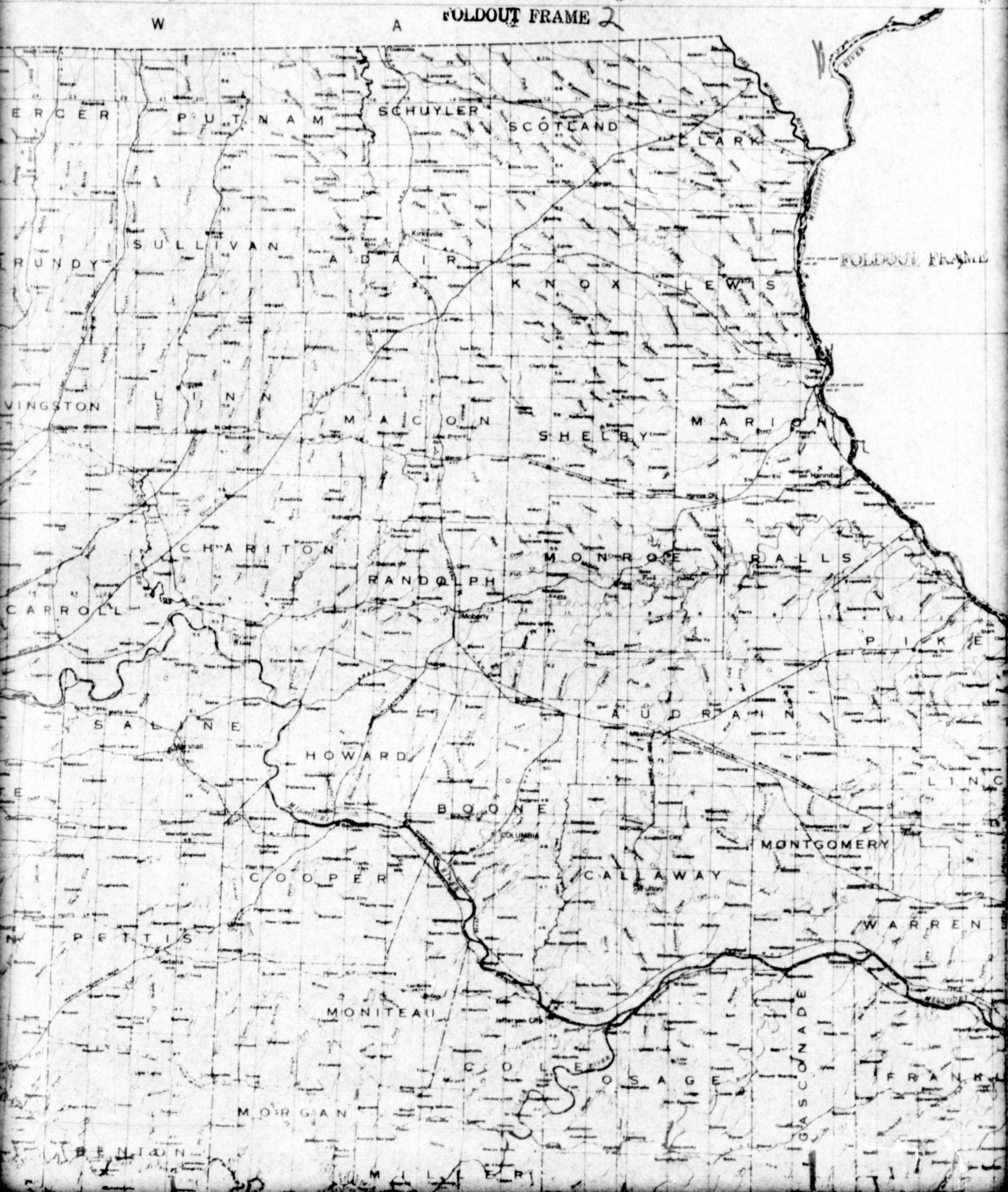




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STATE OF MISSOURI



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Lambert conformal conic projection based on standard parallels 33° and 45°  
1927 North American datum

LEGEND

- ★ State capital
- County seat
- City, town, or village
- ✕ Scheduled service airport
- Built-up area shown for towns over 10,000 population
- County boundary

SOURCE DATA

- U. S. Dept. of the Interior—Geological Survey topographic maps
- U. S. Dept. of the Army—Corps of Engineers topographic maps

POPULATION KEY

|                |                   |
|----------------|-------------------|
| ST LOUIS       | more than 200,000 |
| SPRINGFIELD    | 50,000 to 200,000 |
| Jefferson City | 10,000 to 50,000  |
| West Plains    | 5,000 to 10,000   |
| Houston        | less than 5,000   |

Populations indicated by size of letters

BASE MAP

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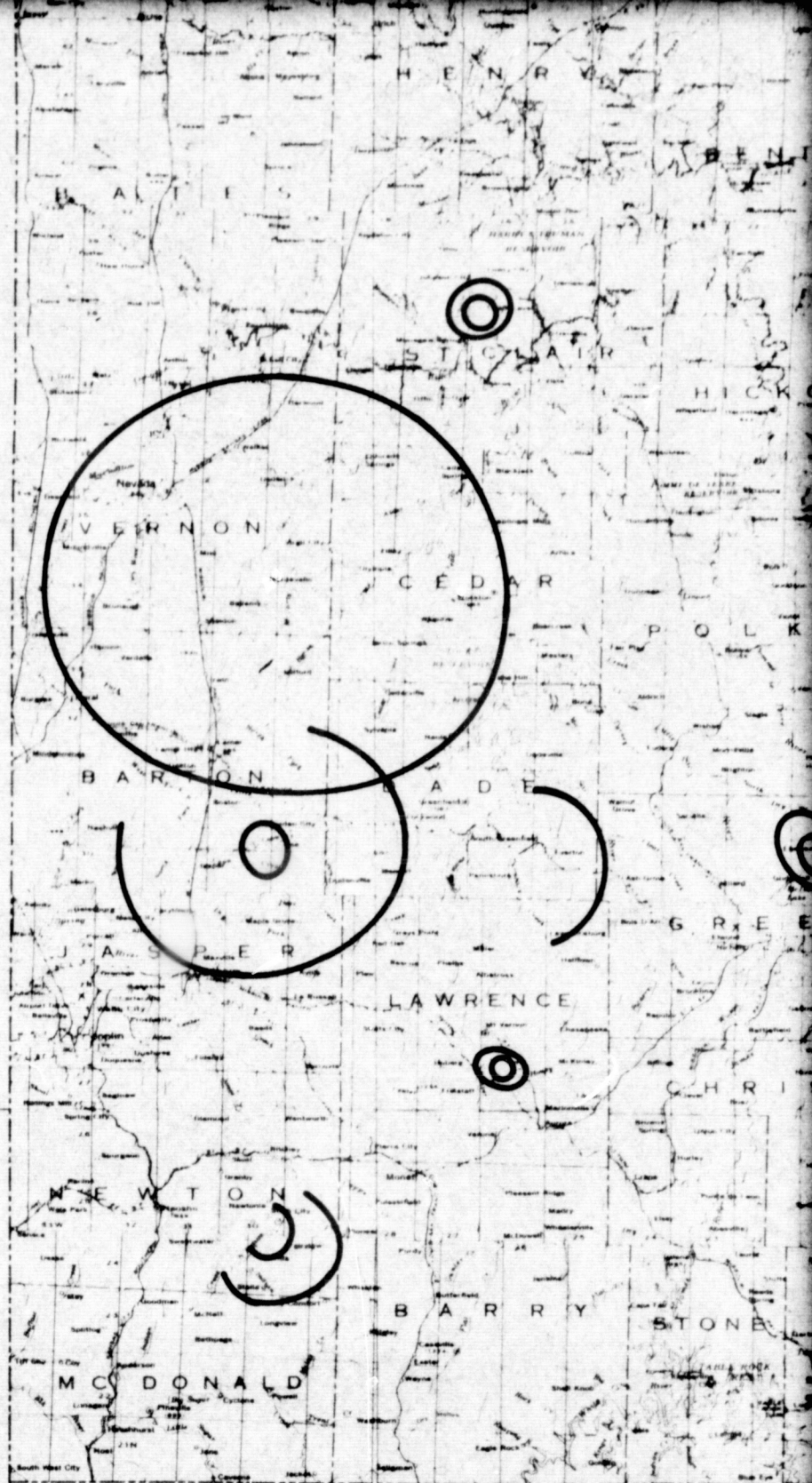
Figure VII-2 Major Circular and Arcuate Traces  
observed on Landsat Imagery.



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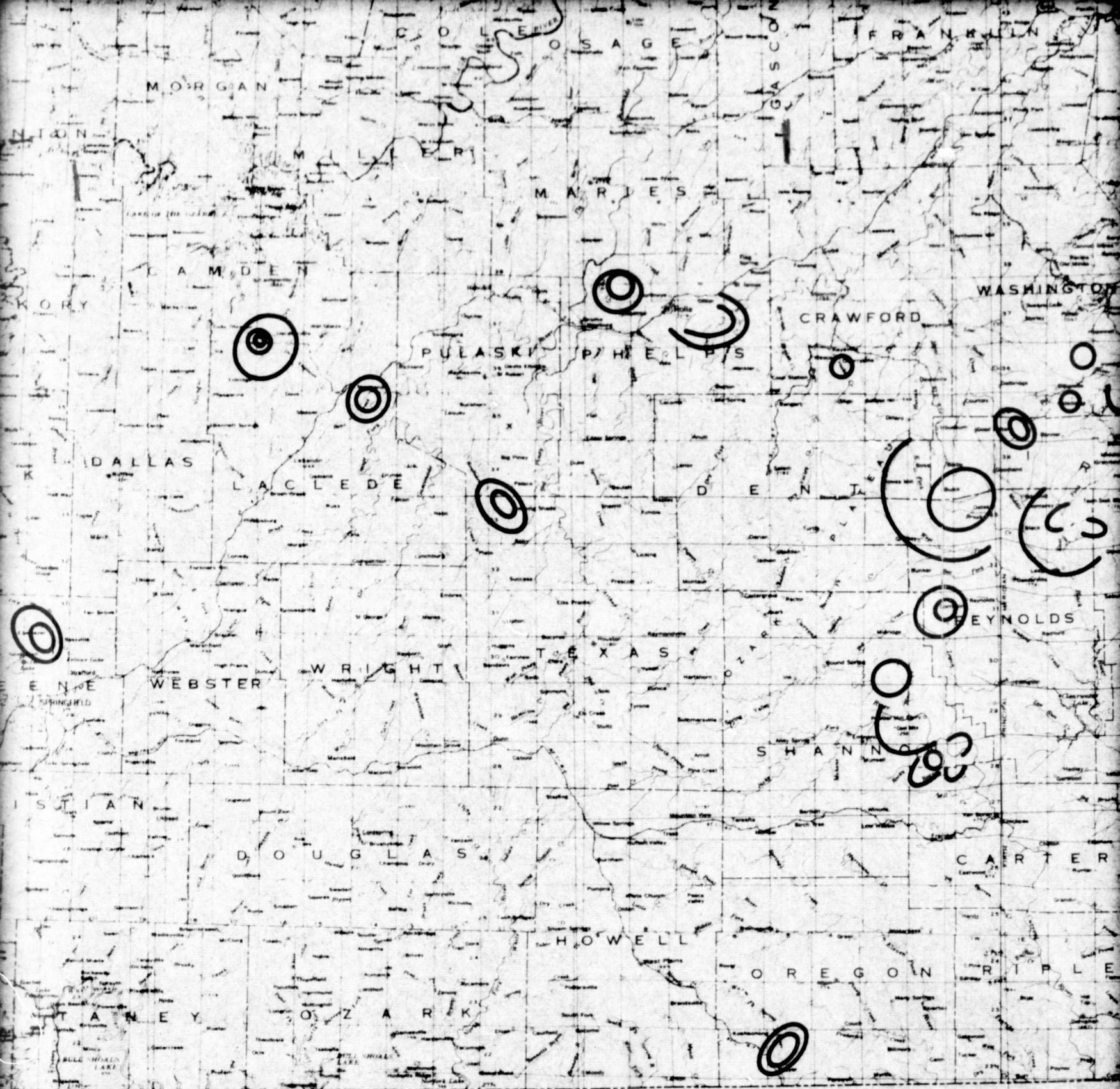
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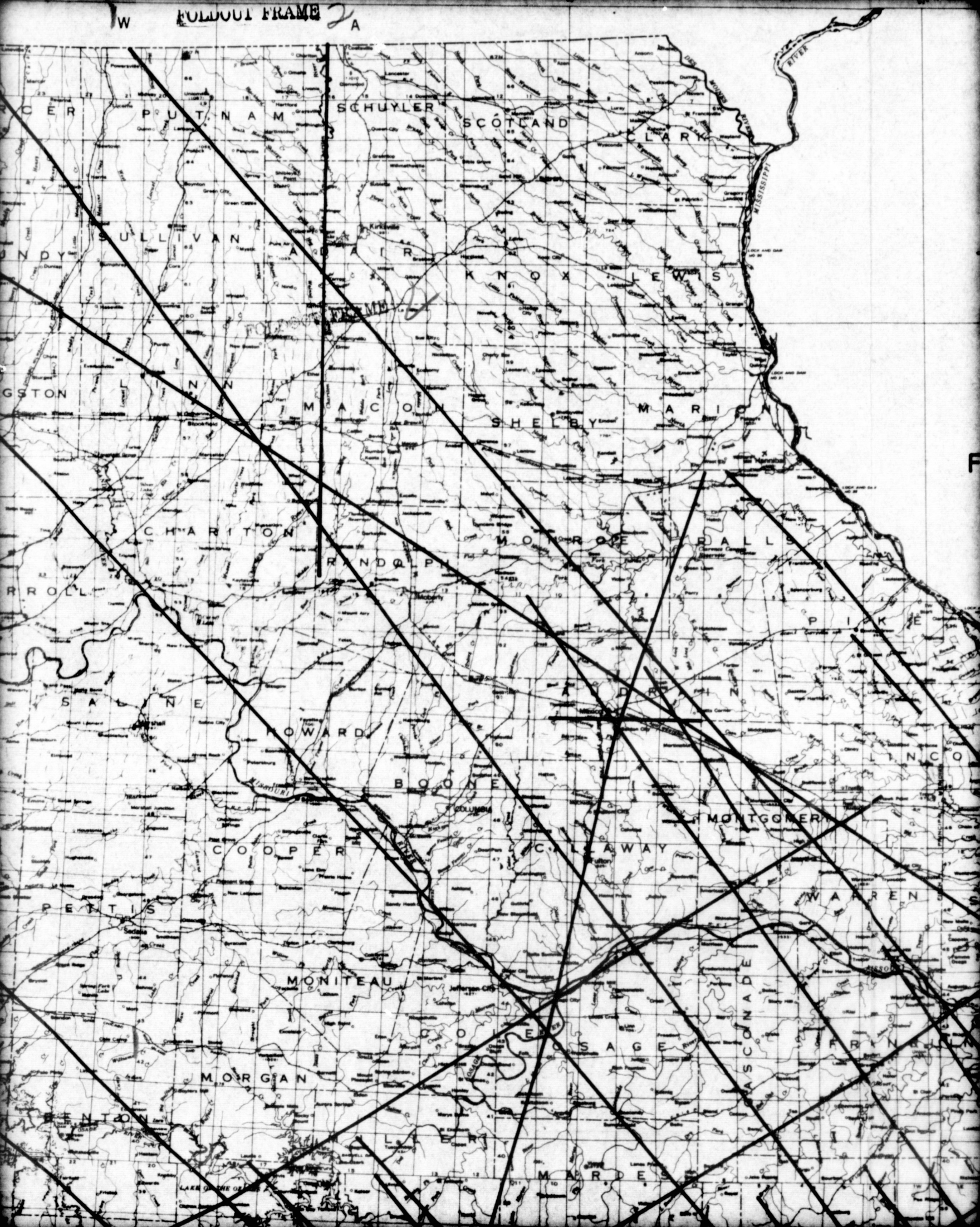
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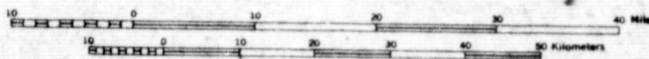




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# STATE OF MISSOURI

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1927 North American datum

#### LEGEND

- State capital
- County seat
- City, town, or village
- ✈ Scheduled service airport
- Built-up area shown for towns over 10,000 population
- County boundary

#### SOURCE DATA

U. S. Dept. of the Interior—Geological Survey topographic maps  
U. S. Dept. of the Army—Corps of Engineers topographic maps

#### POPULATION KEY

|                |                   |
|----------------|-------------------|
| ST LOUIS       | more than 200,000 |
| SPRINGFIELD    | 50,000 to 200,000 |
| Jefferson City | 10,000 to 50,000  |
| West Plains    | 5,000 to 10,000   |
| Hannibal       | less than 5,000   |

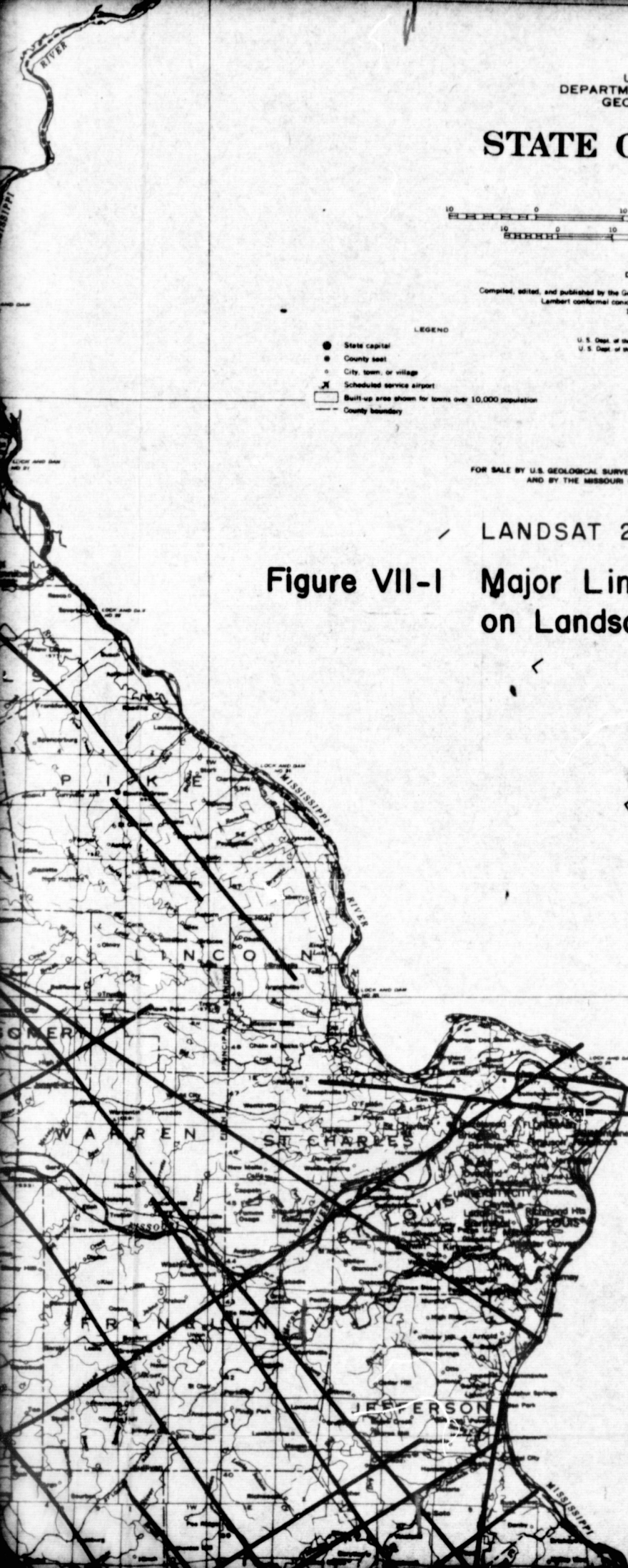
Population indicated by size of letters

BASE MAP

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Figure VII-1 Major Lineaments observed  
on Landsat Imagery.



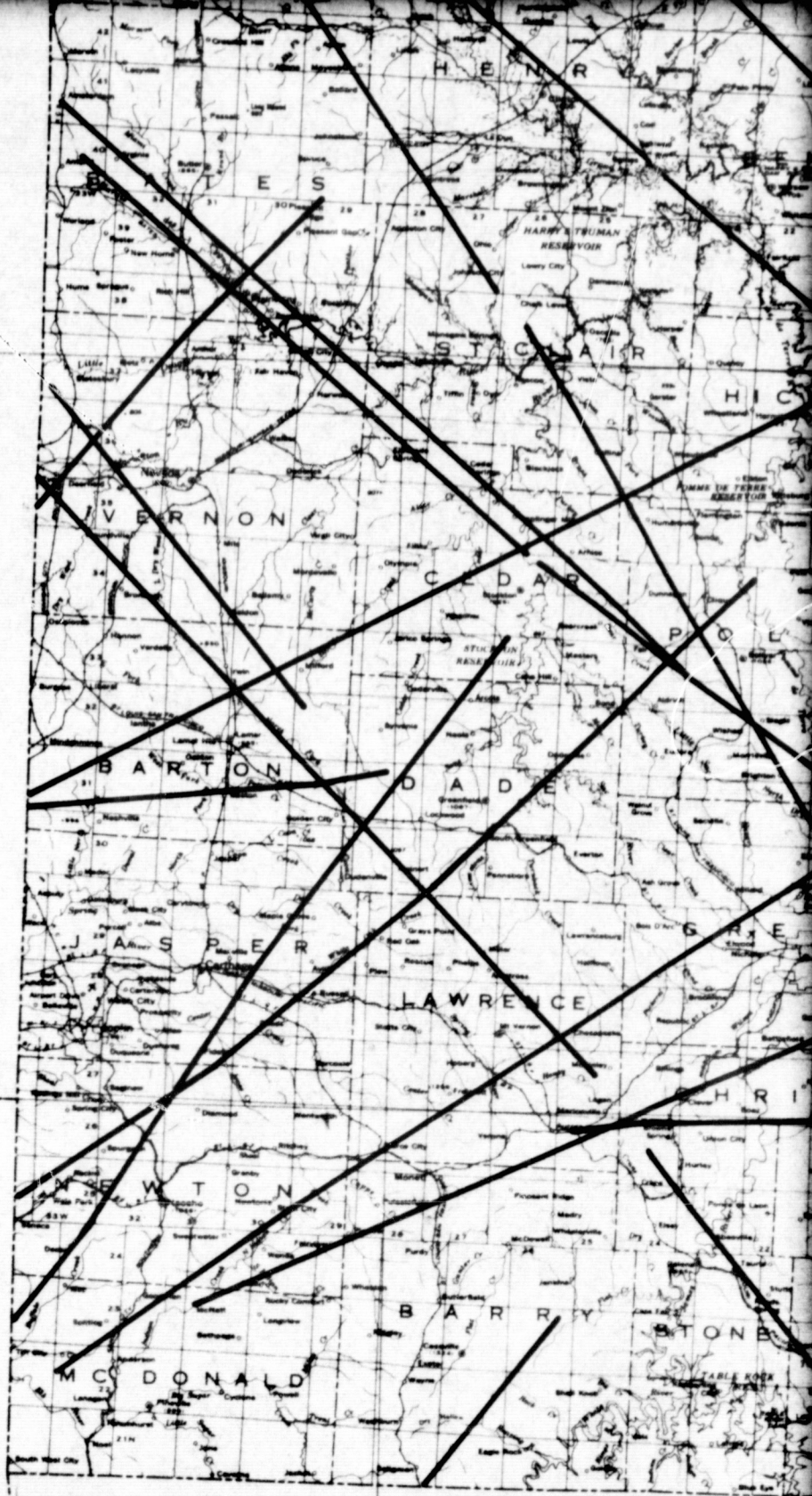
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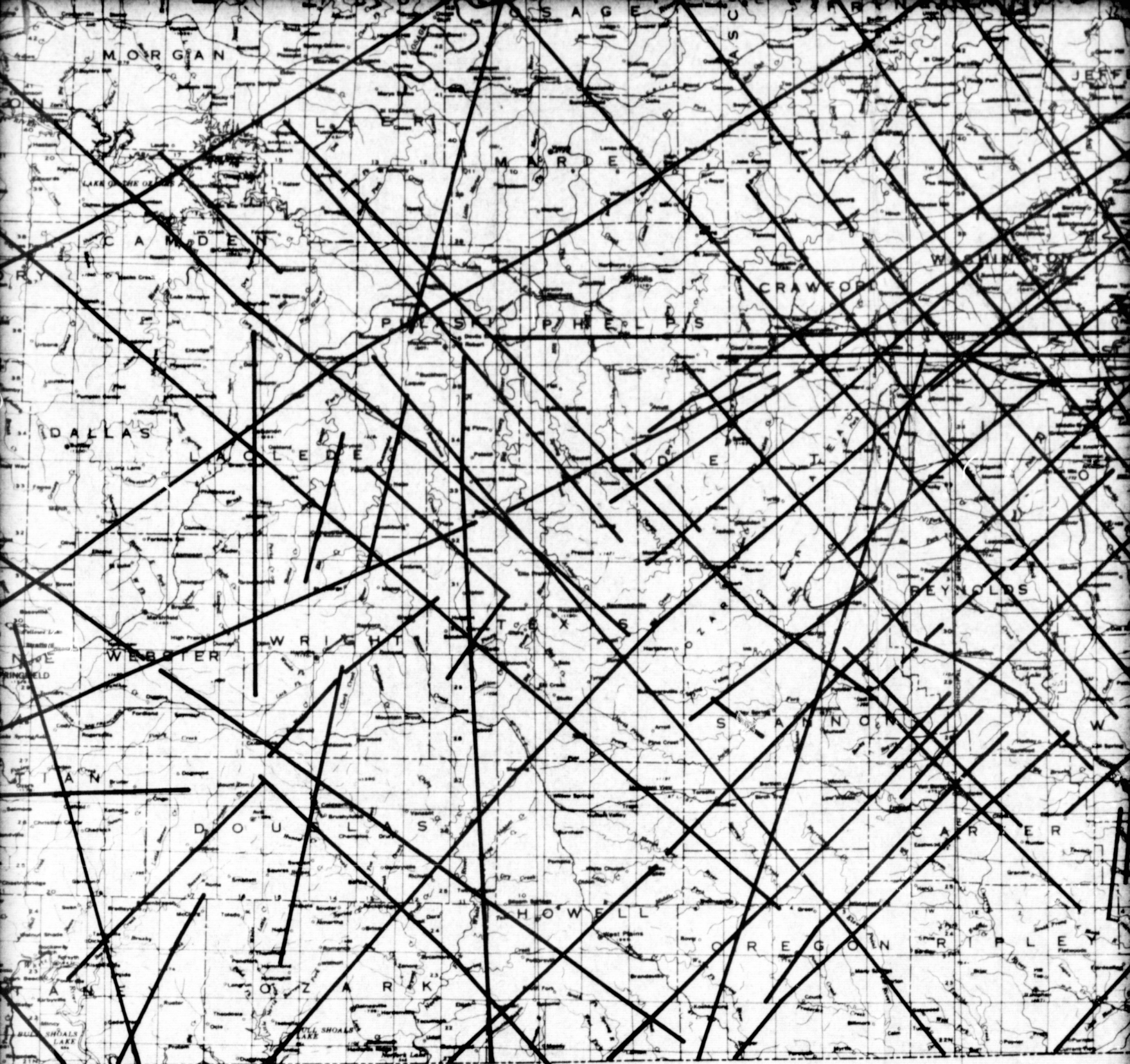
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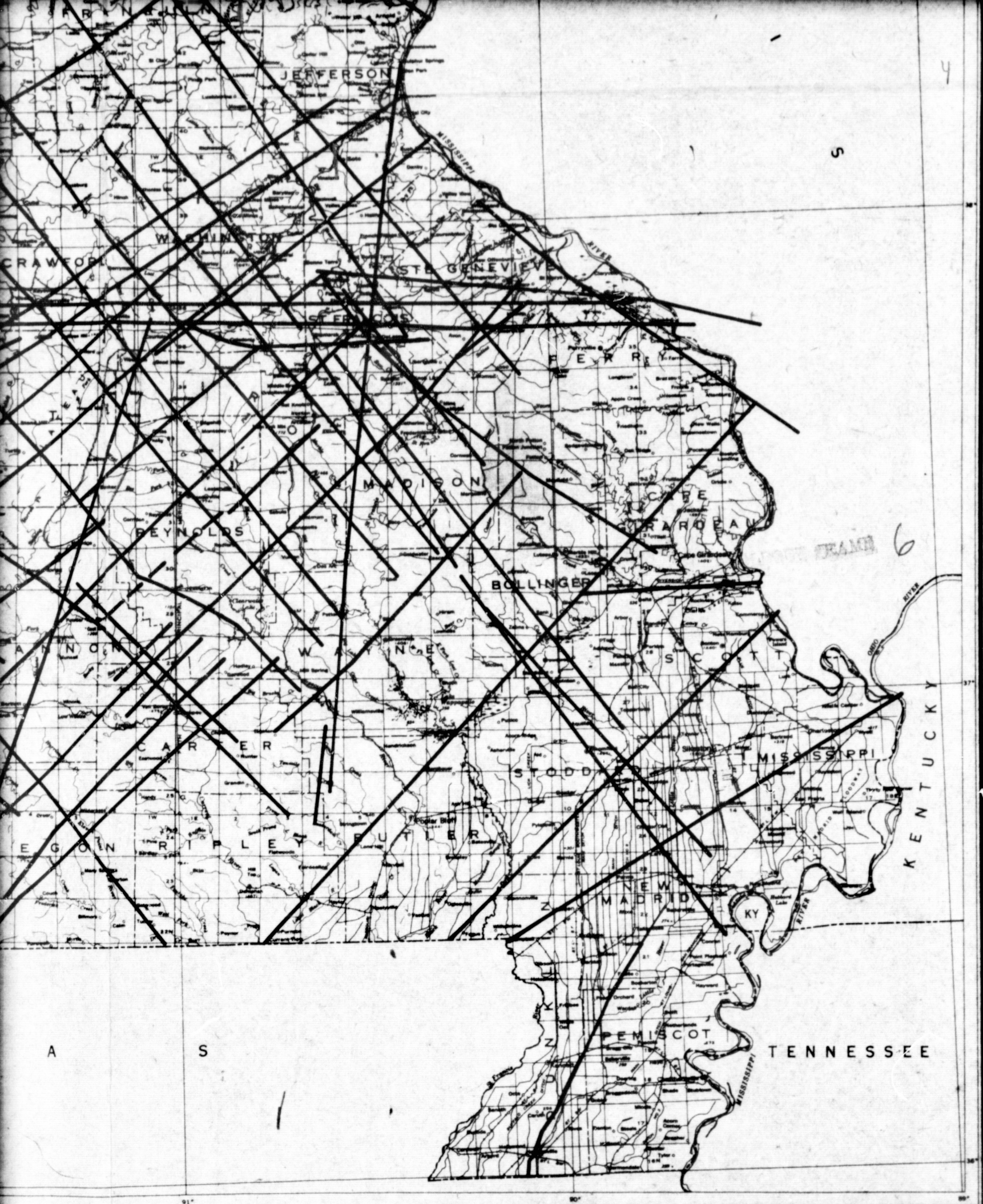


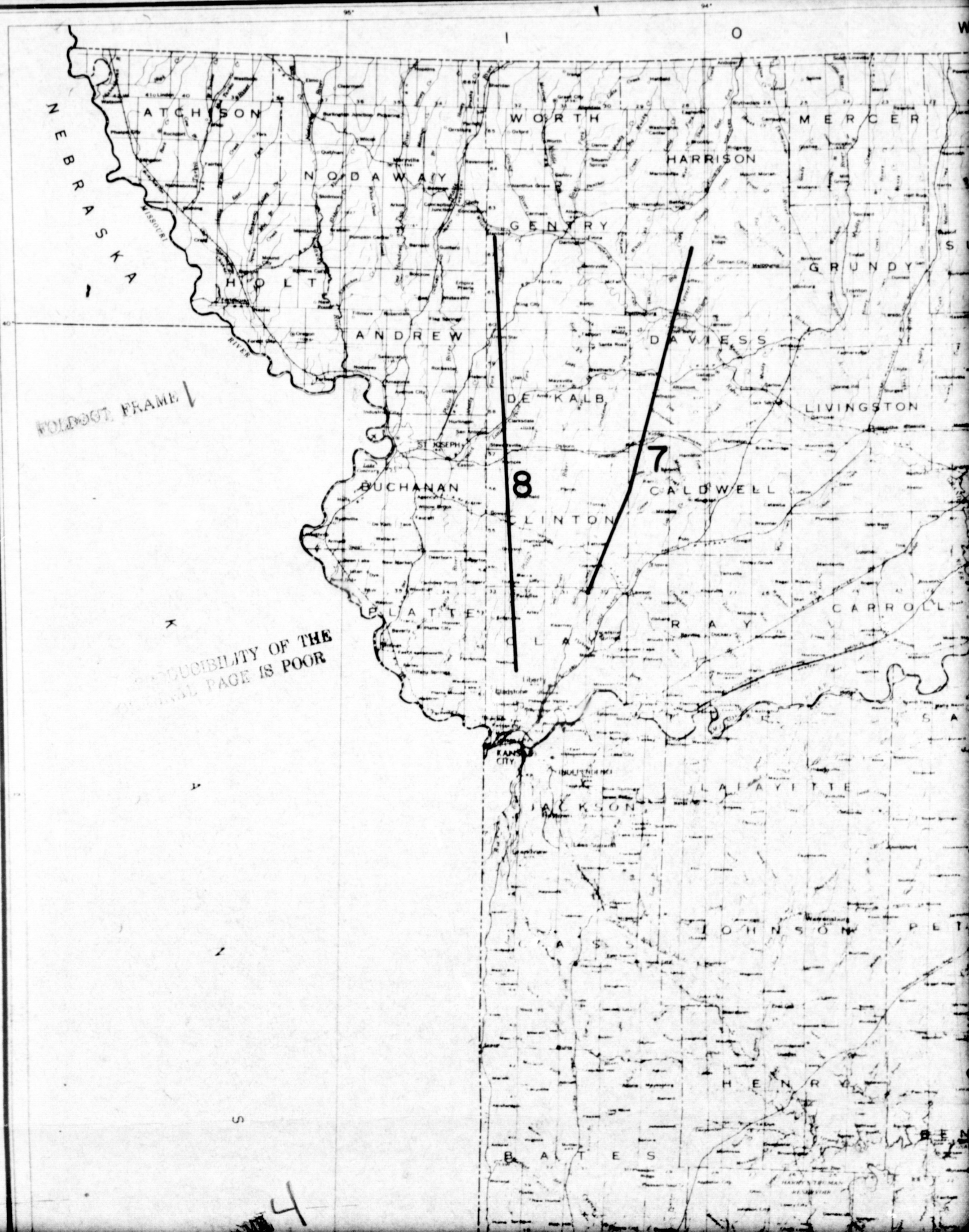


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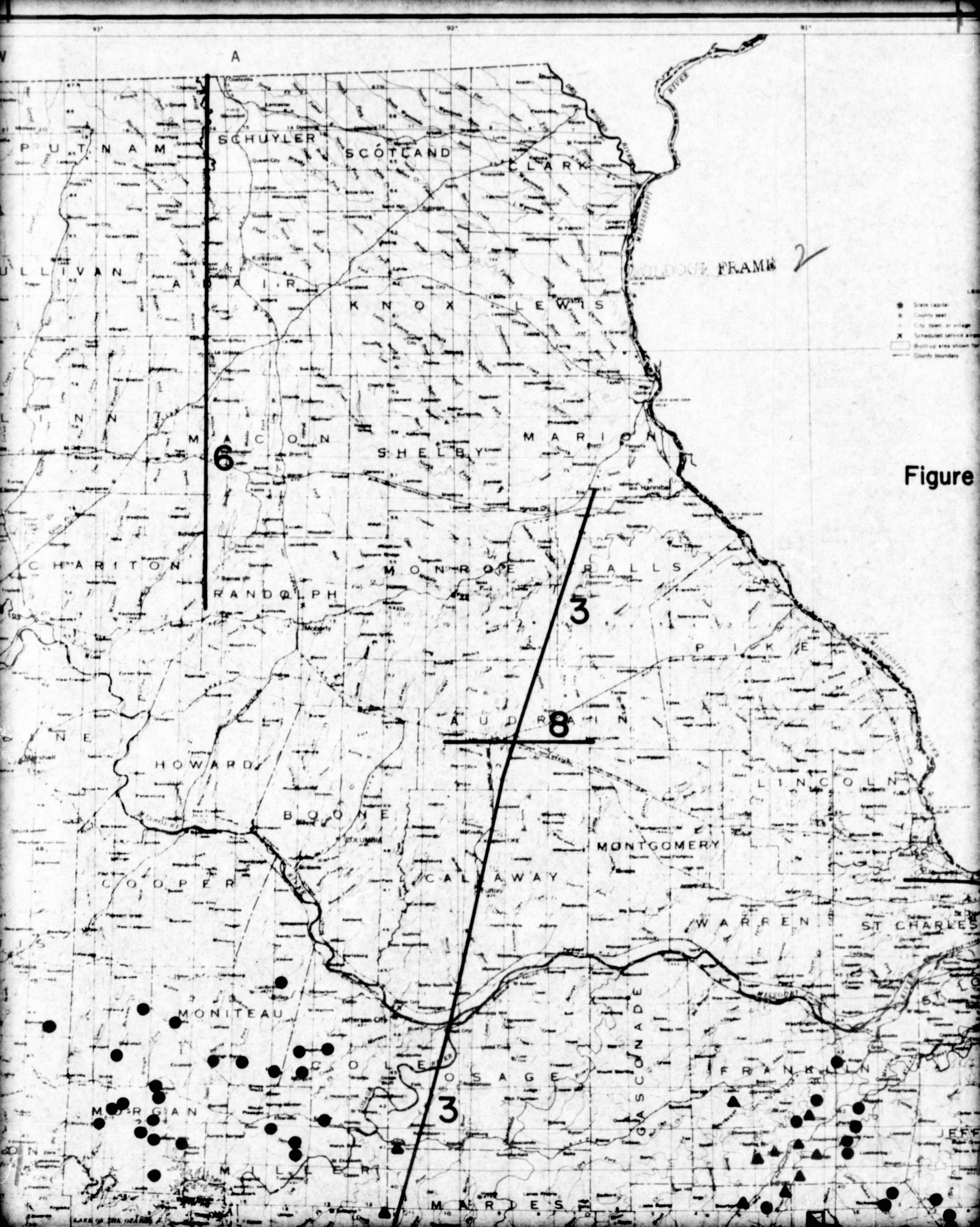


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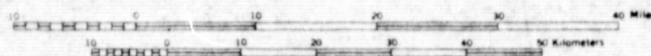




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# STATE OF MISSOURI

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## LEGEND

- ★ State capital
- ✱ County seat
- City, town, or village
- ✈ Scheduled service airport
- Built-up area shown for towns over 10,000 population
- County boundary

## SOURCE DATA

U. S. Dept. of the Interior—Geological Survey topographic maps  
U. S. Dept. of the Army—Corps of Engineers topographic maps

## POPULATION KEY

|   |                   |
|---|-------------------|
| ST. LOUIS                               | more than 700,000 |
| SPRINGFIELD                             | 50,000 to 200,000 |
| Jefferson City                          | 10,000 to 50,000  |
| West Plains                             | 5,000 to 10,000   |
| Population indicated by size of letters | less than 5,000   |

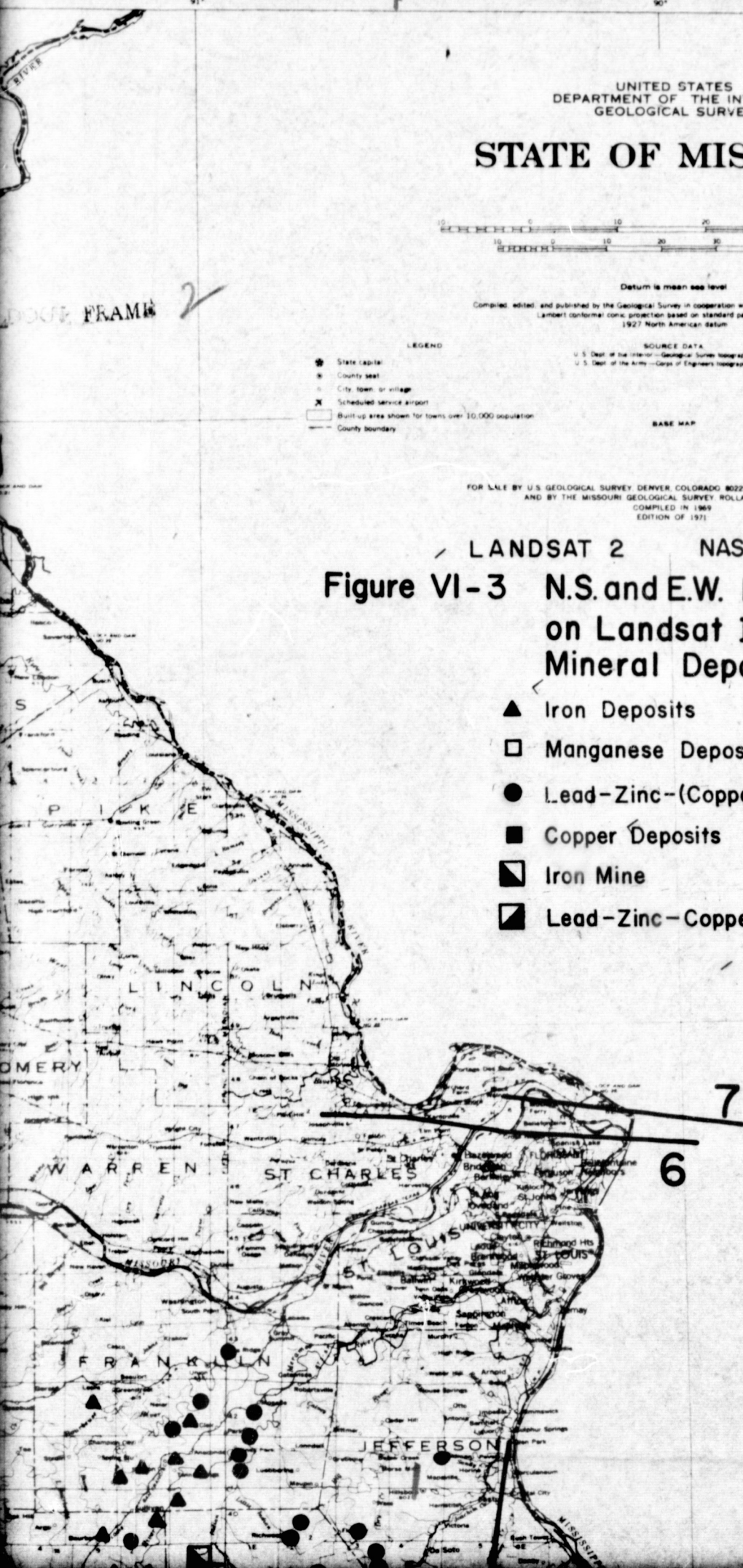
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## Figure VI-3 N.S. and E.W. Lineaments observed on Landsat Imagery and Major Mineral Deposits.

- ▲ Iron Deposits
- Manganese Deposit
- Lead-Zinc-(Copper) Deposits
- Copper Deposits
- ▣ Iron Mine
- ▣ Lead-Zinc-Copper Mine





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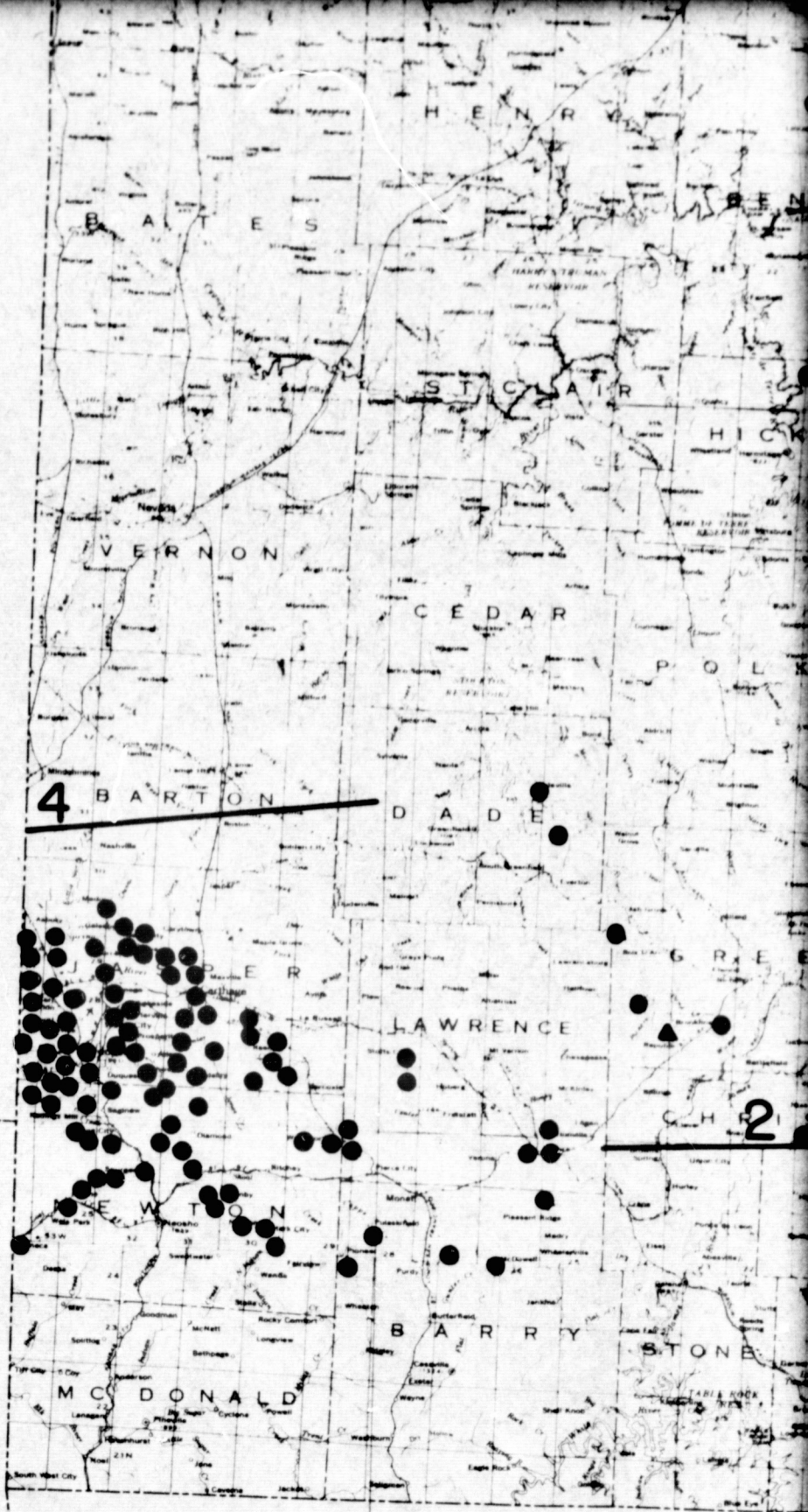
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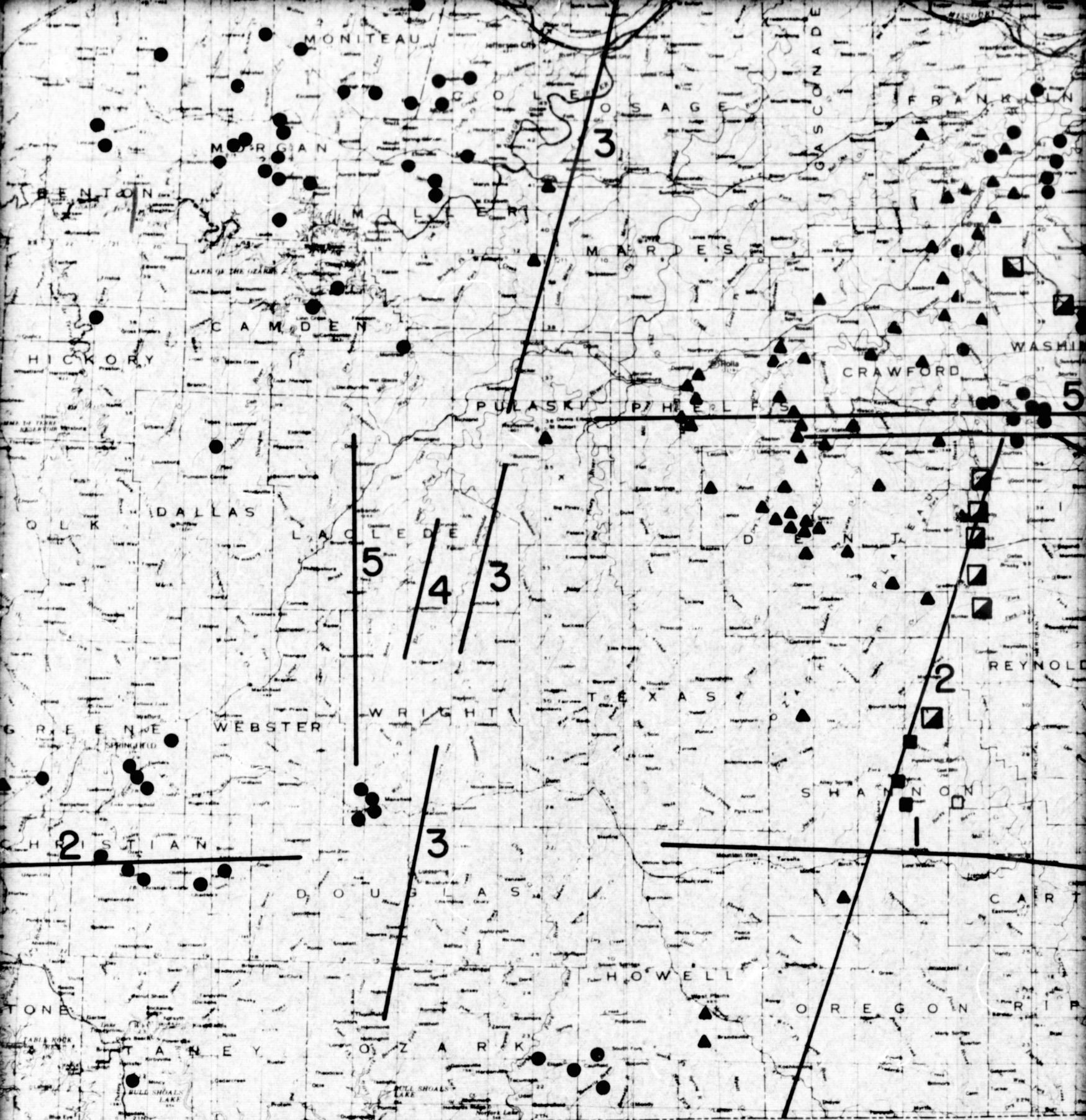
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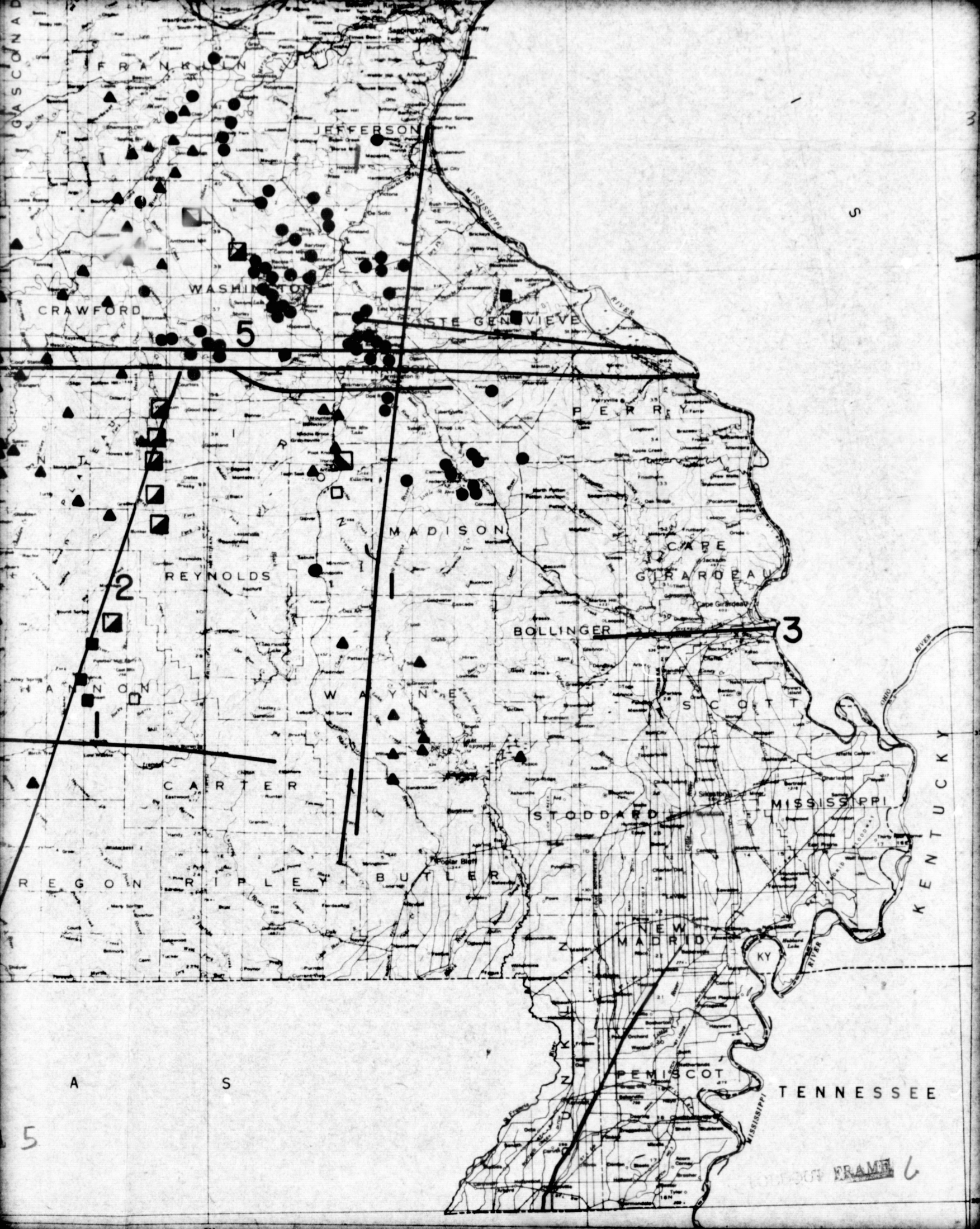


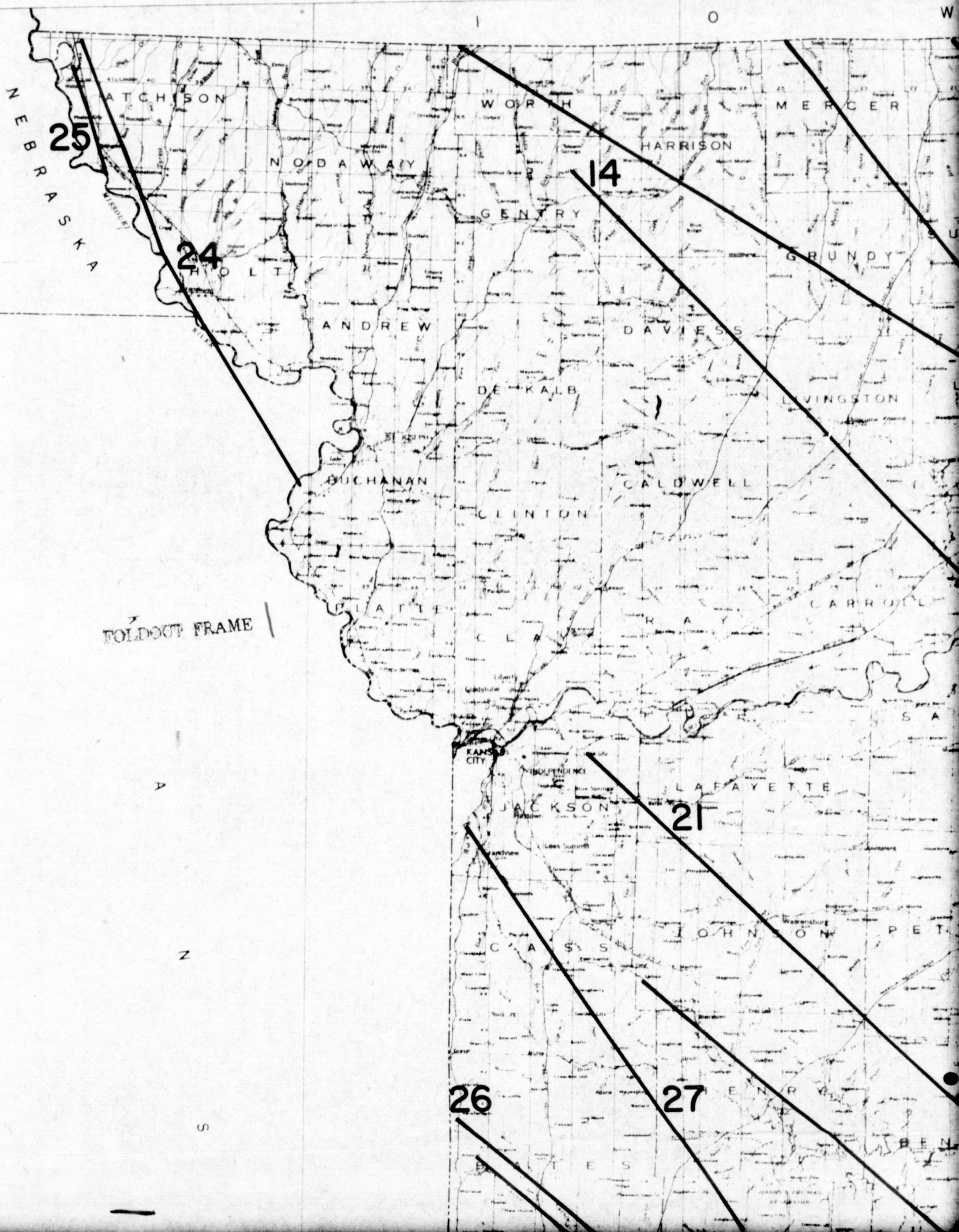


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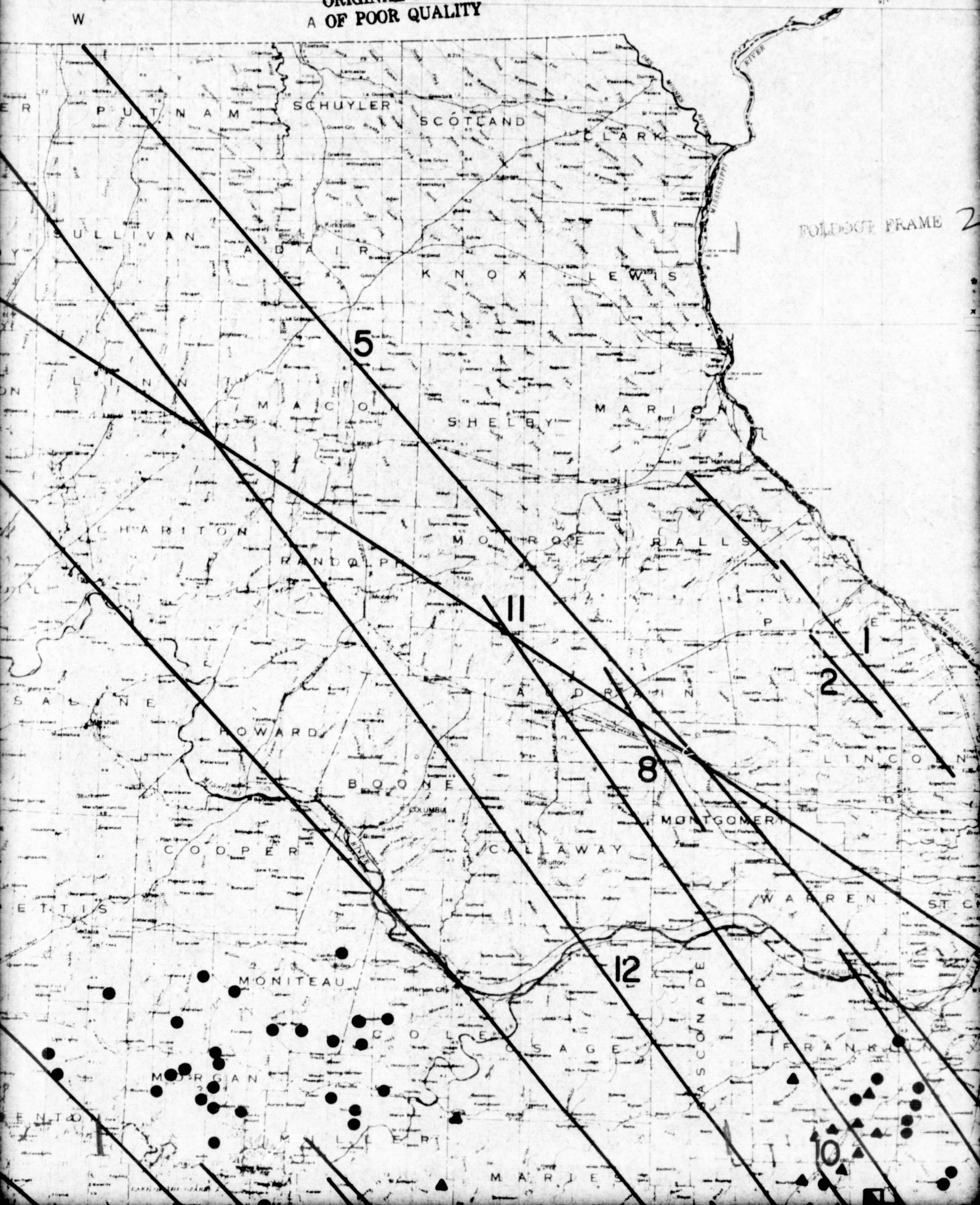


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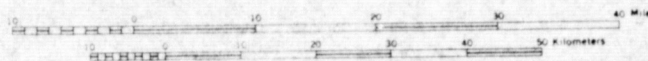
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# STATE OF MISSOURI

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1927 North American datum

- LEGEND
- \* State capital
  - x County seat
  - City, town, or village
  - X Scheduled service airport
  - Built-up area shown for towns over 35,000 population
  - County boundary

SOURCE DATA  
U.S. Dept. of the Interior - Geological Survey topographic maps  
U.S. Dept. of the Army - Corps of Engineers topographic maps

POPULATION KEY

|                |                   |
|----------------|-------------------|
| ST. LOUIS      | More than 200,000 |
| SPRINGFIELD    | 50,000 to 200,000 |
| Jefferson City | 10,000 to 50,000  |
| West Plains    | 5,000 to 10,000   |
| Population     | less than 5,000   |

Population indicated by size of letters

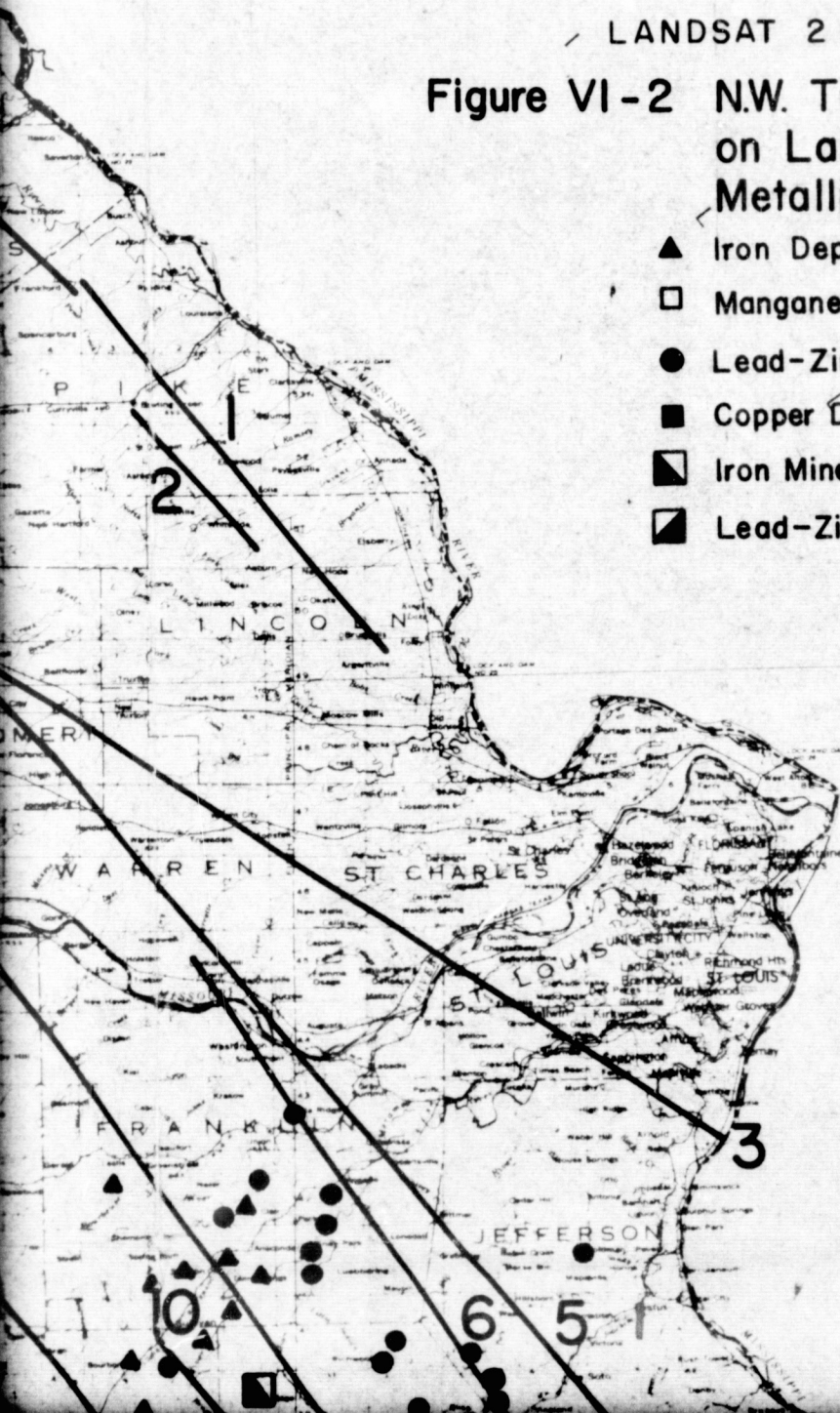
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**Figure VI-2 N.W. Trending Lineaments observed on Landsat Imagery and Major Metallic Mineral Deposits.**

- ▲ Iron Deposits
- Manganese Deposit
- Lead-Zinc-(Copper) Deposits
- Copper Deposits
- ▣ Iron Mine
- ▣ Lead-Zinc-Copper Mine



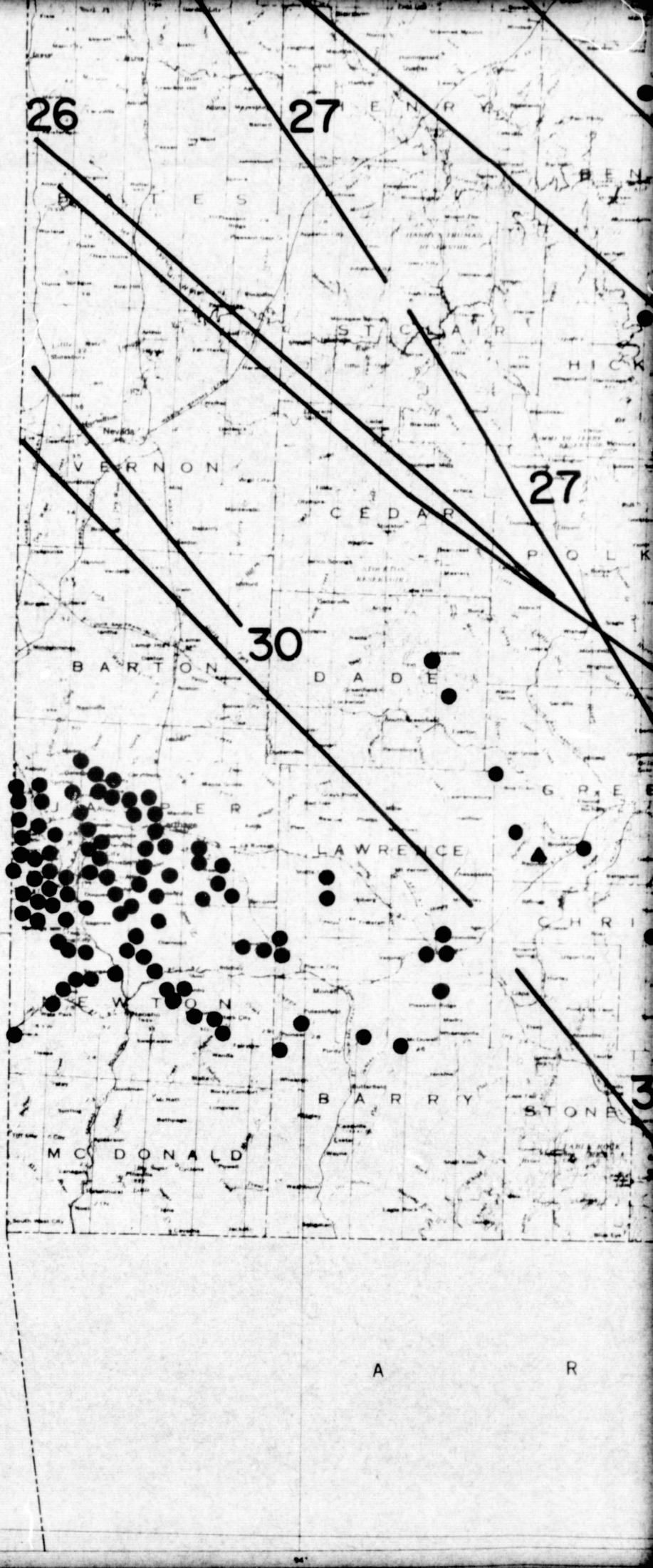
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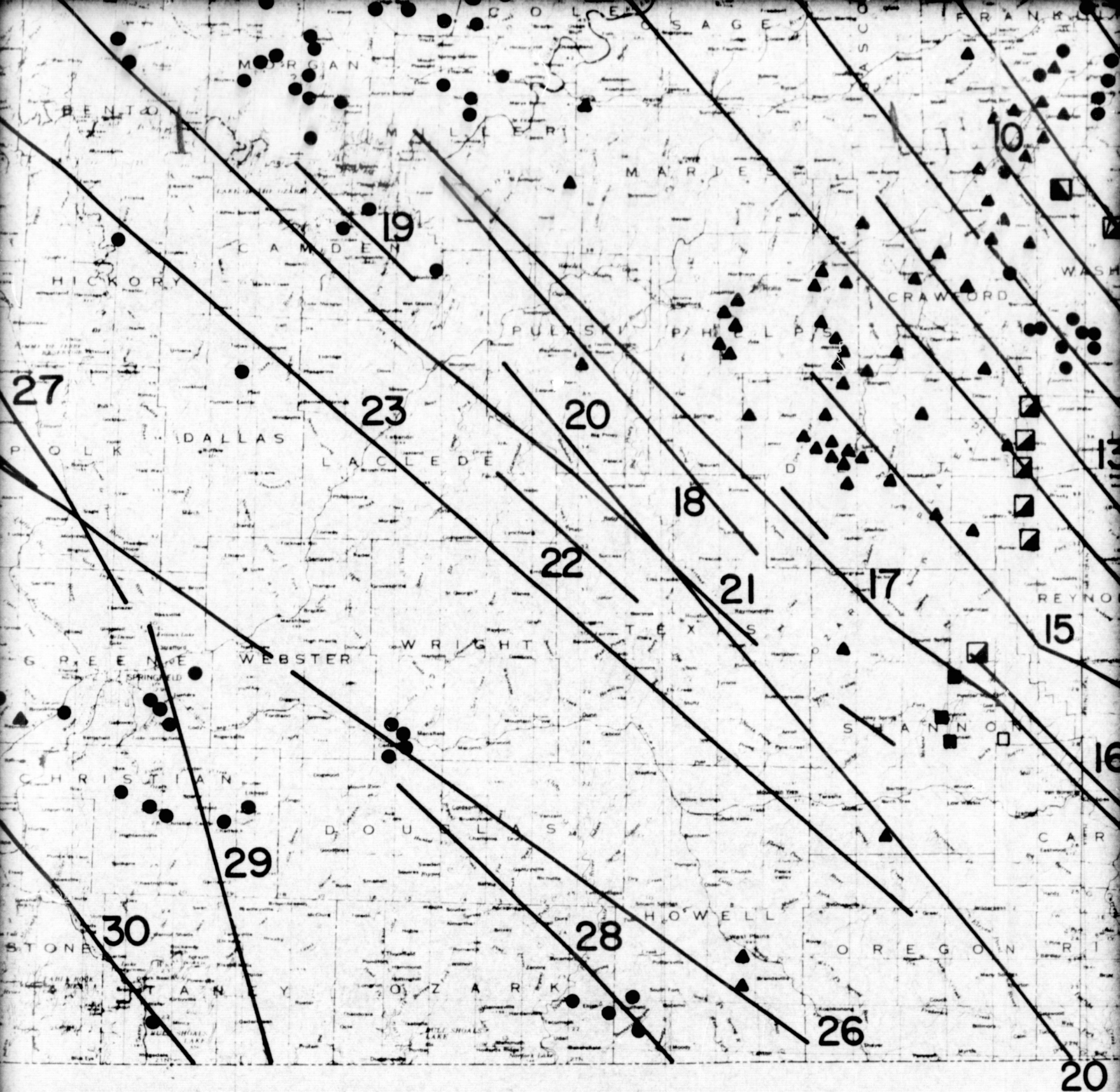


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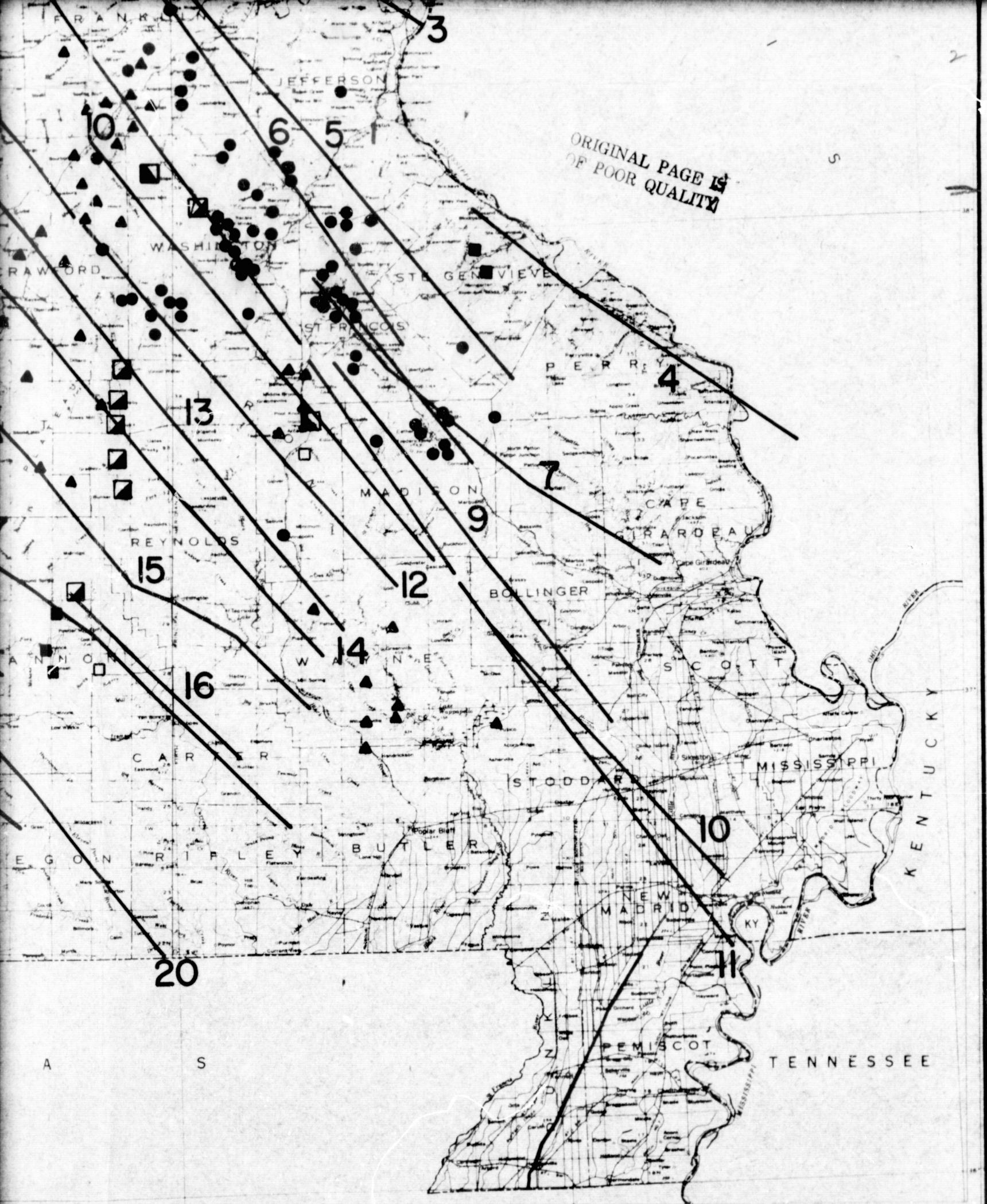
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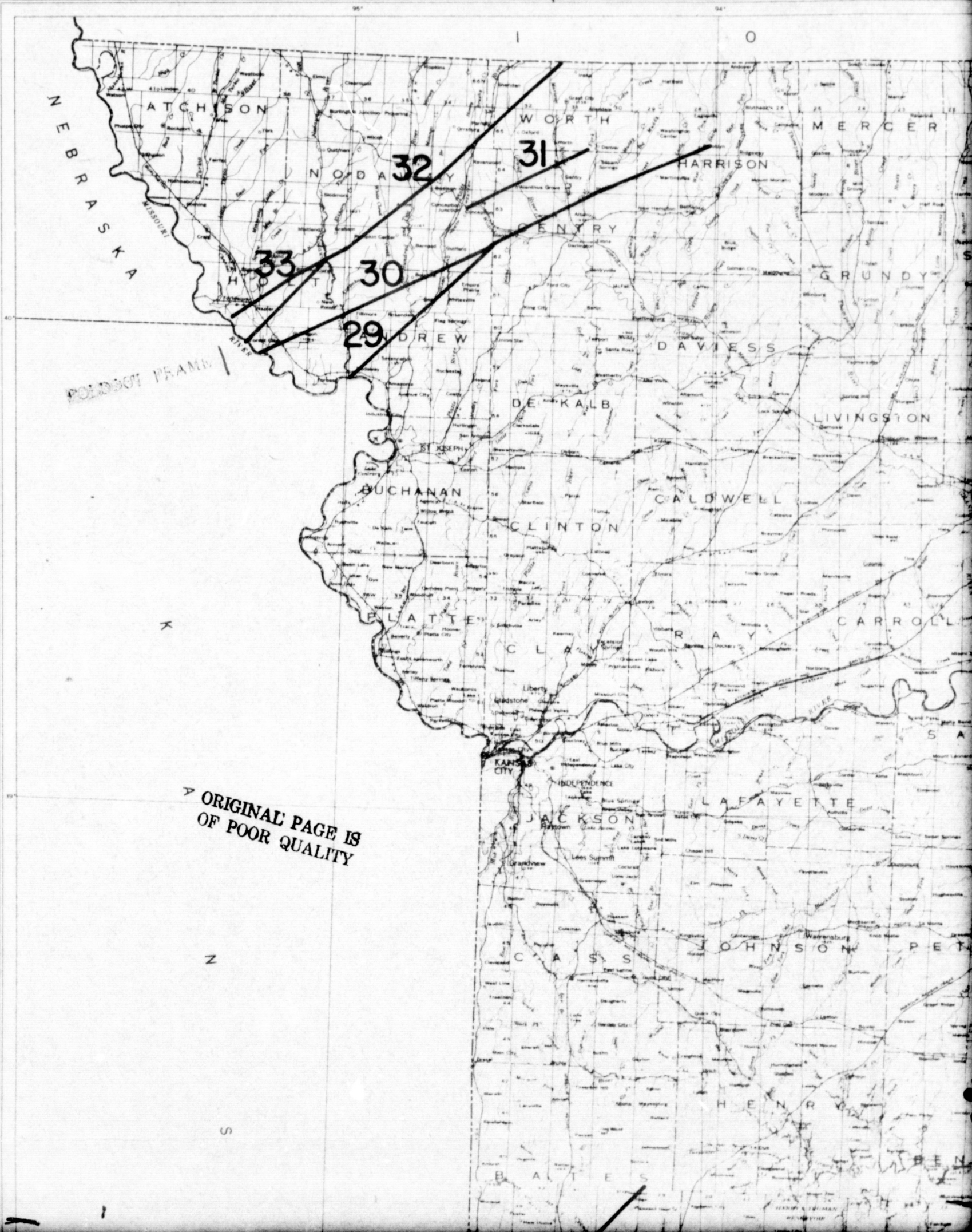


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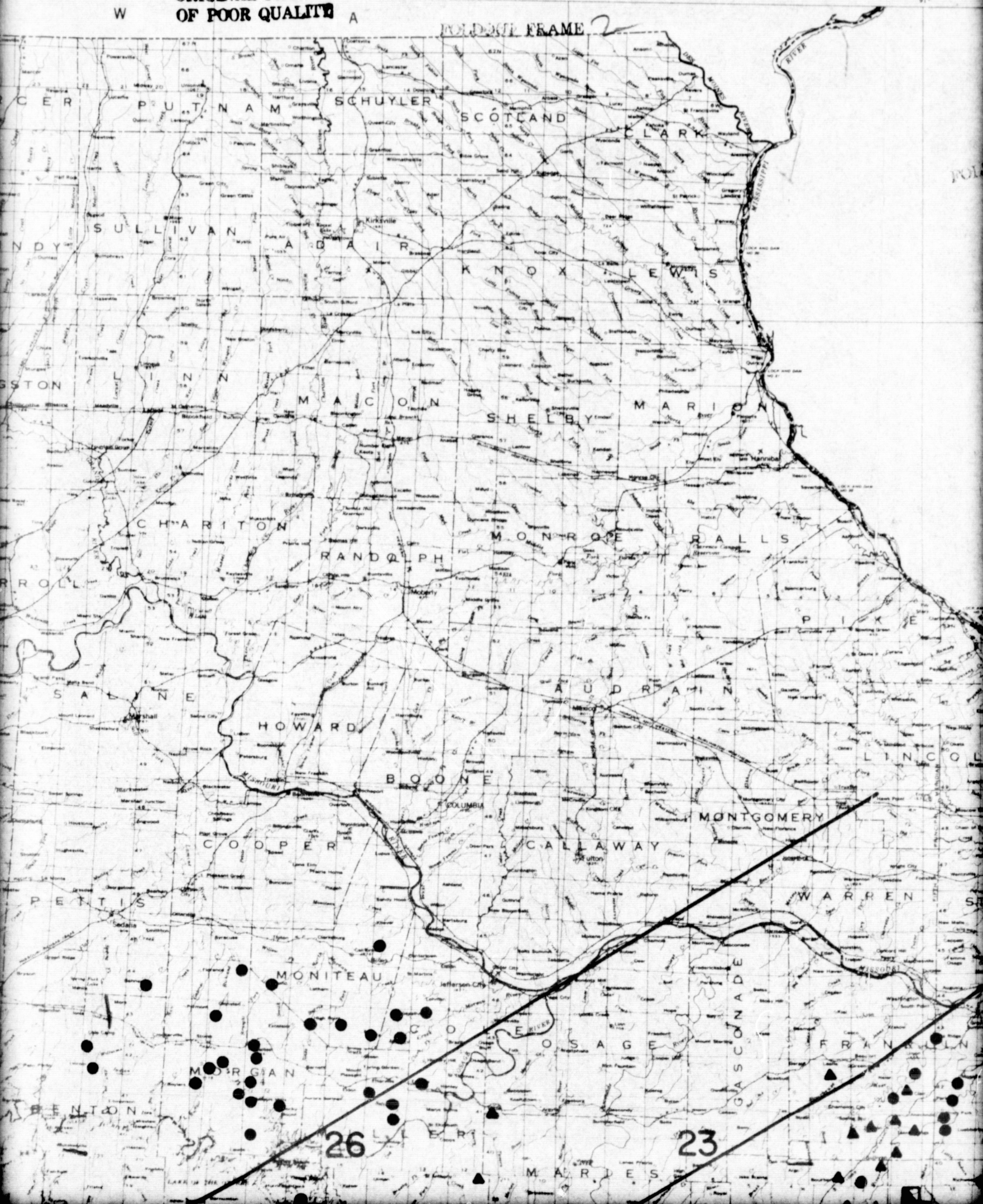
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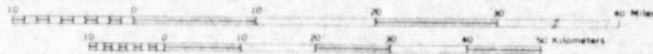




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# STATE OF MISSOURI

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1927 North American Datum

LEGEND

- ★ State capital
- County seat
- City, town, or village
- ✕ Scheduled service airport
- Built-up area shown for towns over 10,000 population
- County boundary

SOURCE DATA

U. S. Dept. of the Interior - Geological Survey topographic maps  
U. S. Dept. of the Army - Corps of Engineers topographic maps

POPULATION REL

ST LOUIS  
SPRINGFIELD  
Jefferson City  
West Plains  
Hannibal

More than 200,000  
50,000 to 200,000  
10,000 to 50,000  
5,000 to 10,000  
less than 5,000

Population indicated by size of letters

BASE MAP

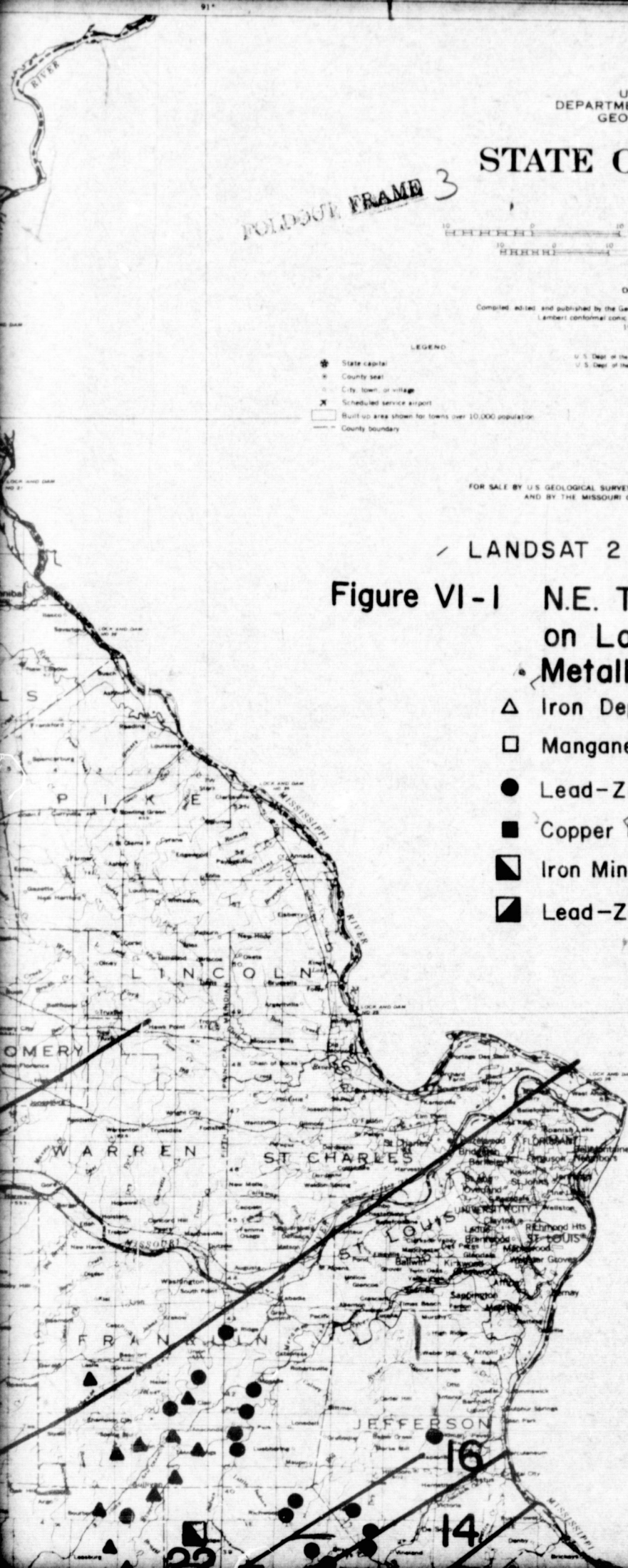
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## Figure VI-1 N.E. Trending Lineaments observed on Landsat Imagery and Major Metallic Mineral Deposits.

- △ Iron Deposits
- Manganese Deposit
- Lead-Zinc-(Copper) Deposits
- Copper Deposits
- ▣ Iron Mine
- ▤ Lead-Zinc-Copper Mine

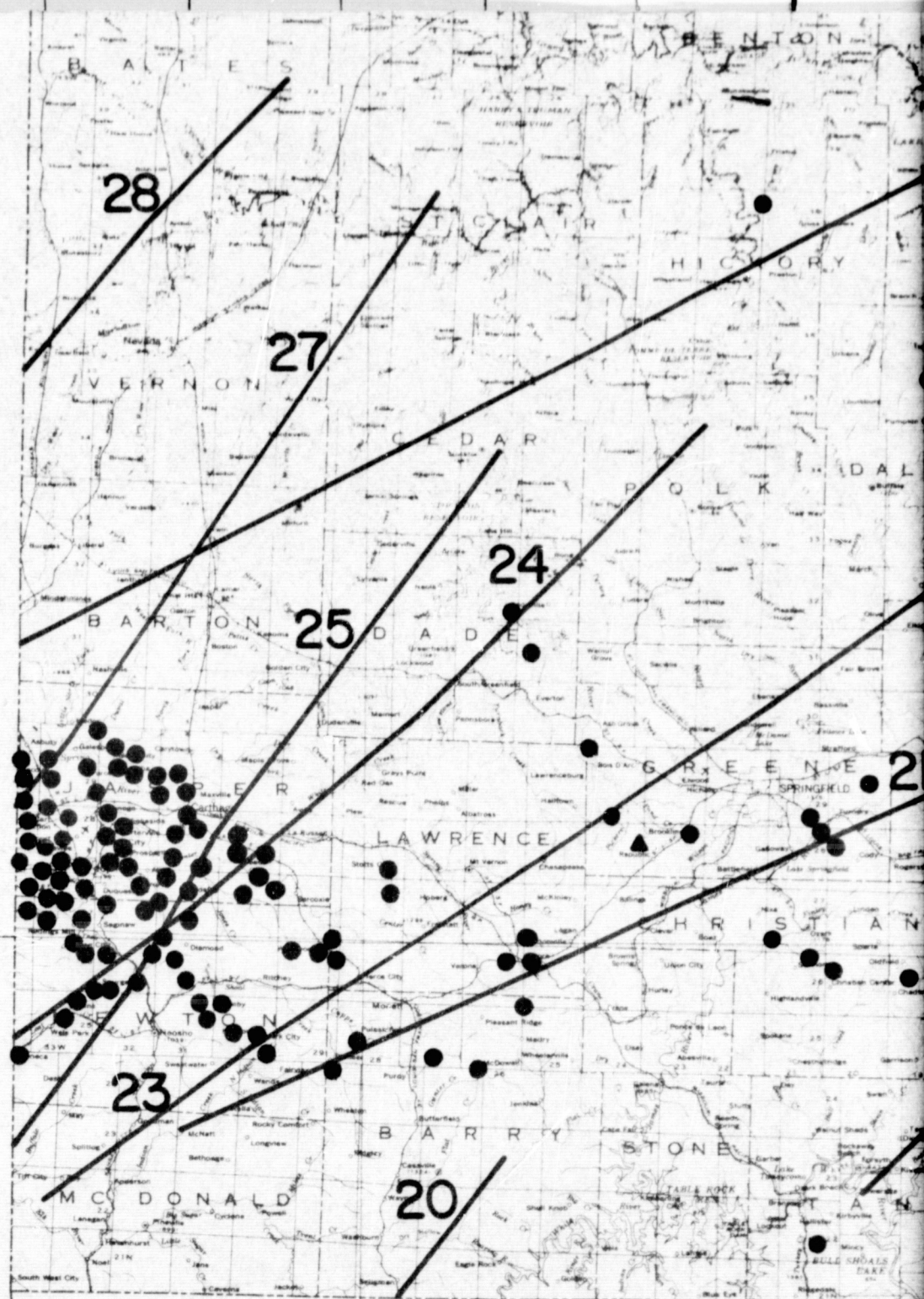
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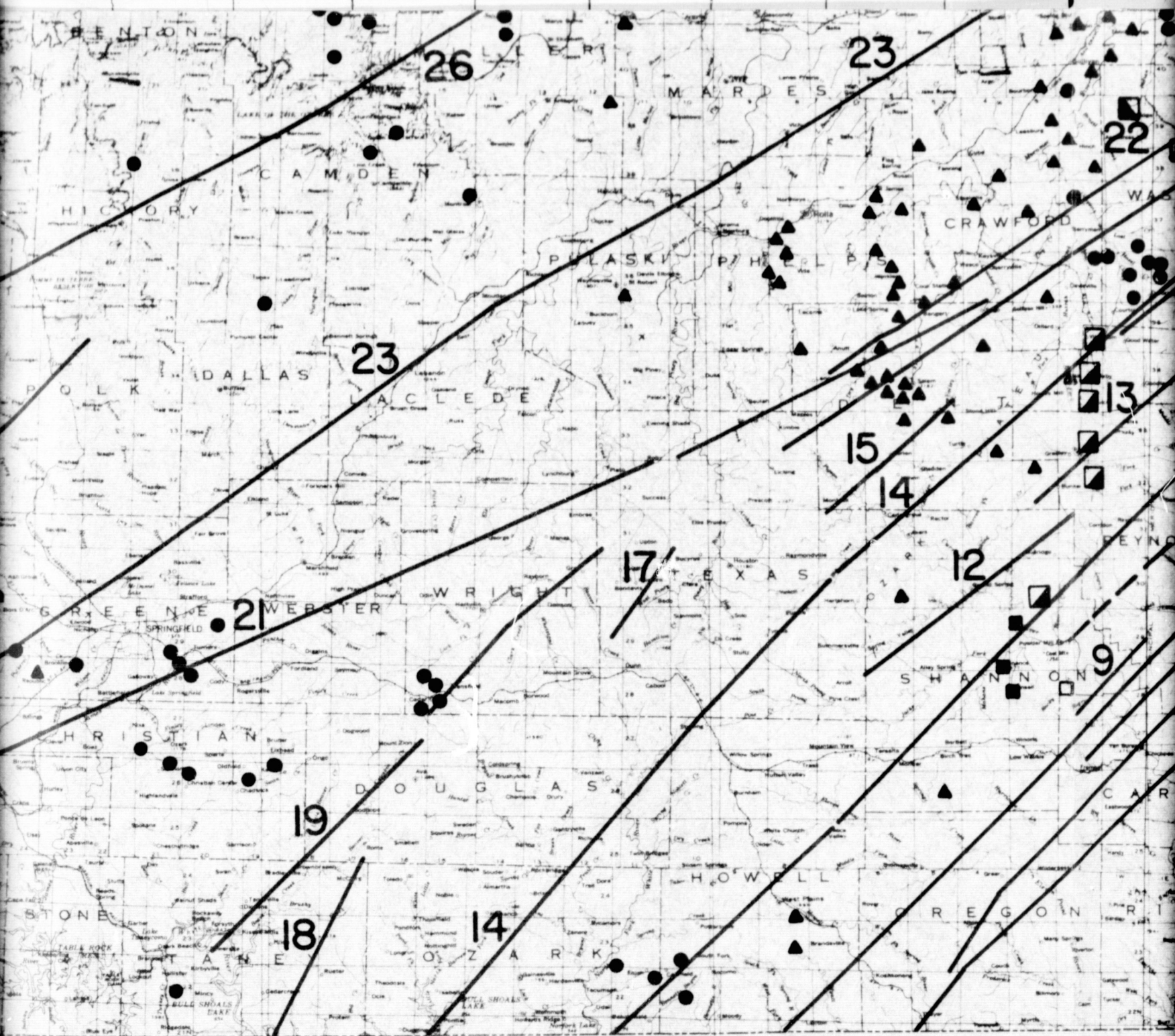




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